JUNE 1958

THE WELDING JOURNAL

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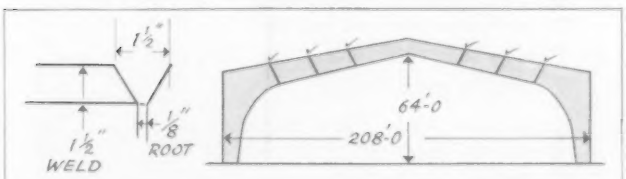

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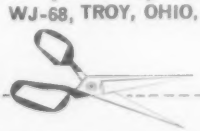

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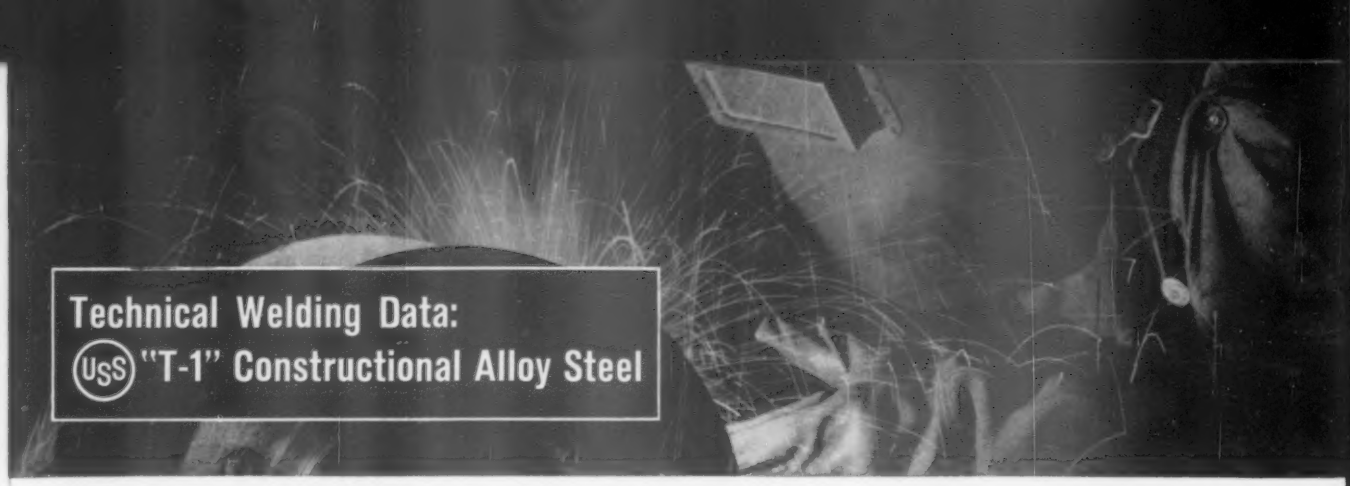

Technical Welding Data:
USS "T-1" Constructional Alloy Steel

Control heat input when welding USS "T-1" Steel

USS "T-1" Steel is unlike many structural carbon and alloy steels—steels which require preheating before welding to ensure desirable microstructure in the heat-affected zone. Extensive experience over the years with fabricators of this constructional alloy steel has demonstrated that preheating is not generally necessary. Without it, either low carbon martensite or bainite is formed and these are microstructures of more than adequate toughness. With "T-1"* Steel, any process which tends to diminish the quenching capacity of the base metal, such as preheating or excessive heat input during welding, is likely to reduce the after-weld cooling rate so much as to form undesirable microstructures.

There are cases, however, when preheating is recommended. These may occur when welding involves one or more of the following factors: high restraint, moisture on the steel, electrodes not low enough in moisture content, and low-ductility weld metal. In the case of high restraint, for example, preheating can reduce the cooling rate of highly restrained, high-strength weld metal so that microfissuring does not develop. But it is essential to *control* heat input and preheat to within safe limits or loss of toughness in the heat-affected zone is likely.

The accompanying table suggests limits for heat input and preheat. These limits are based on published results of laboratory studies conducted at Rensselaer Polytechnic Institute using Charpy V-notch impact specimens of "T-1" Steel. In compiling the table, heat inputs were arbitrarily selected so that a toughness level of 10 ft-lbs at minus 50°F would be obtained. These heat input limits can be relaxed or made more restrictive whenever less or greater toughness is desired. Heat input, expressed as Watt-seconds/inch (Joules/inch) can be computed from a simple formula that relates current, voltage, and electrode travel speed.

$$\text{HEAT INPUT (Watt-seconds/inch) or (Joules/inch)} = \frac{\text{Amps x Arc Volts x 60}}{\text{Speed (Inches per min.)}}$$

Suggested maximum heat input for welding USS "T-1" Steel
Values in Watt-seconds/inch

Preheat and Interpass Temperature	Plate Thickness						
	¼"	½"	¾"	1"	1¼"	1½"	2"
70°F	36 000	70,000	121,000	any	any	any	any
200°F	29,000	56,000	99,000	173,000	any	any	any
300°F	24,000	47,000	82,000	126,000	175,000	any	any
350°F	21,500	43,500	73,500	109,500	151,000	any	any
400°F	19,000	40,000	65,000	93,000	127,000	165,000	any

To illustrate the use of the table, assume that a multiple-pass buttweld is to be made in a ½-inch-thick plate and no preheating is to be done. The welding conditions selected for the first pass might be 220 amperes, 24 volts, and 5 inches per minute. Substituting these values in the formula, a heat input of 63,360 Watt-seconds/inch is obtained. This input would be tolerable since it is below the 70,000 maximum in the table. If by the time the next pass is to be made, the joint has cooled to ambient temperature, the same welding conditions could be used for subsequent passes. If, however, the joint were short and the welding heat accumulates in the plate to such an extent that the interpass temperature exceeds 200°F, the same conditions should not be used; either current or speed should be varied so that the heat input does not exceed the 56,000 Watt-seconds per inch shown in the table. The same precautions should be applied to all subsequent passes.

It will be noted that only in the relatively thin plates are the limits restrictive; in the thick plates, the limits present no hardship.

The values given in the table are applicable to manual metal-arc welding with a covered electrode and to automatic submerged-arc welding. Despite the use of a high current for automatic submerged-arc welding, the heat input is often less than that normal for manual welding owing to the greater speed of the automatic process. On the other hand, semi-automatic submerged-arc welding may have to be controlled more carefully because of lesser and non-uniform speed.

Write for complete information about the application and fabrication of USS* "T-1" Steel. United States Steel, Room 5604, 525 William Penn Place, Pittsburgh 30, Pennsylvania.

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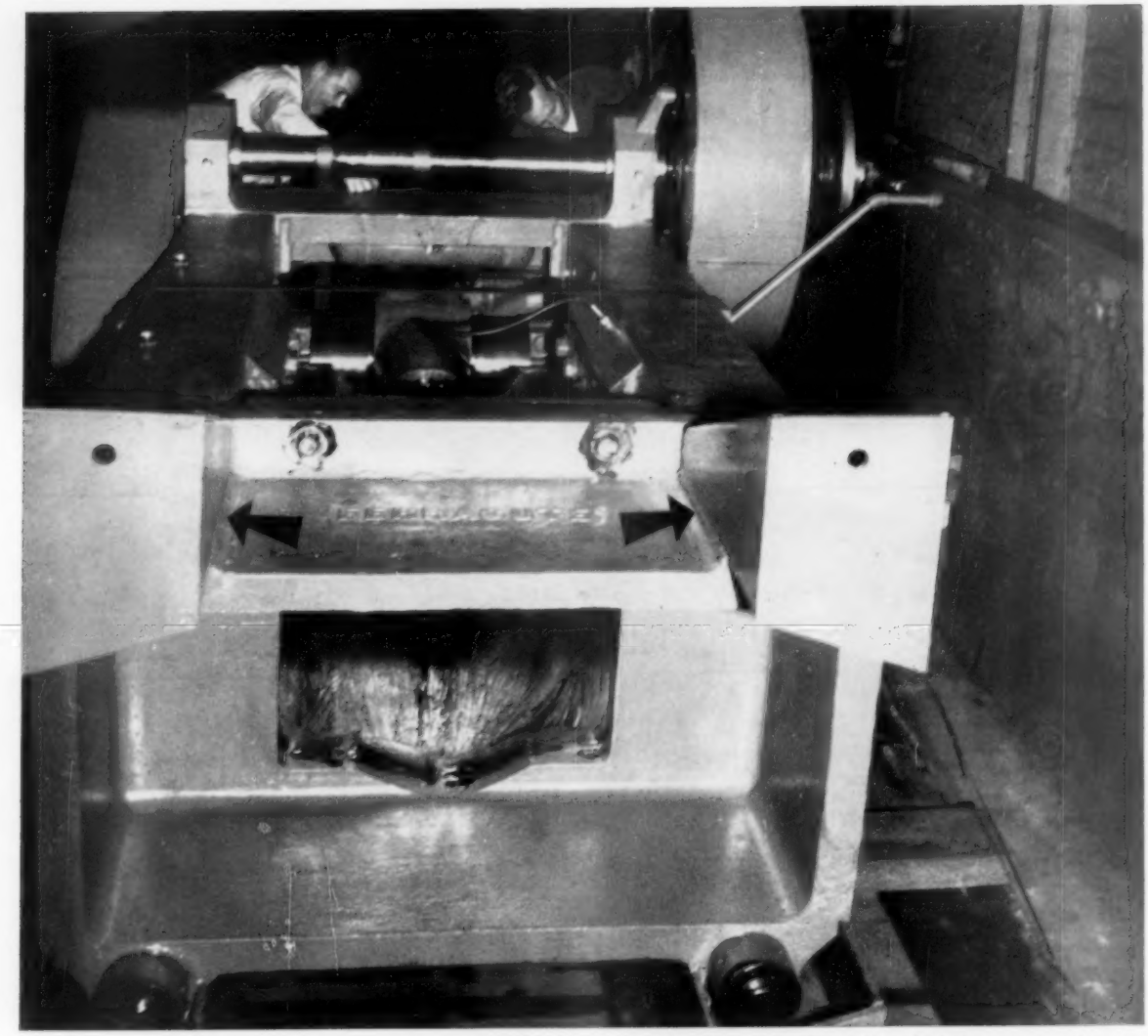

On its side, this 325 ton stamping press shows where fabricated steel legs are welded to the ductile iron base with Ni-Rod "55". Using ductile iron in head and bed, designer was able to drop press height two feet, and cut dead weight considerably.

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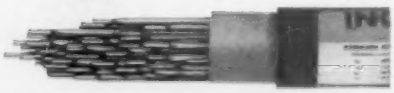

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FOREIGN LITERATURE ENLARGES OUR HORIZON

The average American welding specialist, who reads the American welding magazines carefully every month, practically never sees even the outside cover of any of the foreign welding magazines and books.

It is well known in science and engineering that we pay a heavy price if we neglect overseas' achievements as reflected in the foreign technical press. This is true especially in welding. There are at least fifty foreign magazines devoted wholly or largely to welding. The average caliber of the articles in many of these is fully equal to the caliber of WELDING JOURNAL papers. To ignore these publications is to miss contact with foreign welding specialists who may be able to teach us a great deal.

Product design is one of the fields to which foreign magazines devote considerable space. Often the foreign equipment is basically the same as ours. Sometimes there are ingenious improvements in detail. And sometimes, too, the foreign equipment or welded product represents a new concept. Our designers and manufacturers cannot afford to lose touch with welding progress abroad.

Welding research is another field in which attention to foreign developments always is rewarding. Foreign research organizations regularly assign a man or a team to projects that we have either not tackled or approached with different techniques. For example, a foreign group may have used oscilloscopes to study certain electrical phenomena in welding, where we may have relied on high-speed photography for the same purpose. It behooves us to study the results from abroad to enlarge and perhaps correct our views.

Foreign welding literature is an effective introduction to the foreign welding market and to foreign patents and codes. It deals with these subjects as well as with practical welding techniques.

Many of the contributors of articles to welding magazines beyond our shores have high competence in welding and are worth our attention. Most of us have not awakened to the existence of first-class foreign welding literature. A little time spent reading a few of the best foreign welding journals should quickly convince us of their value.

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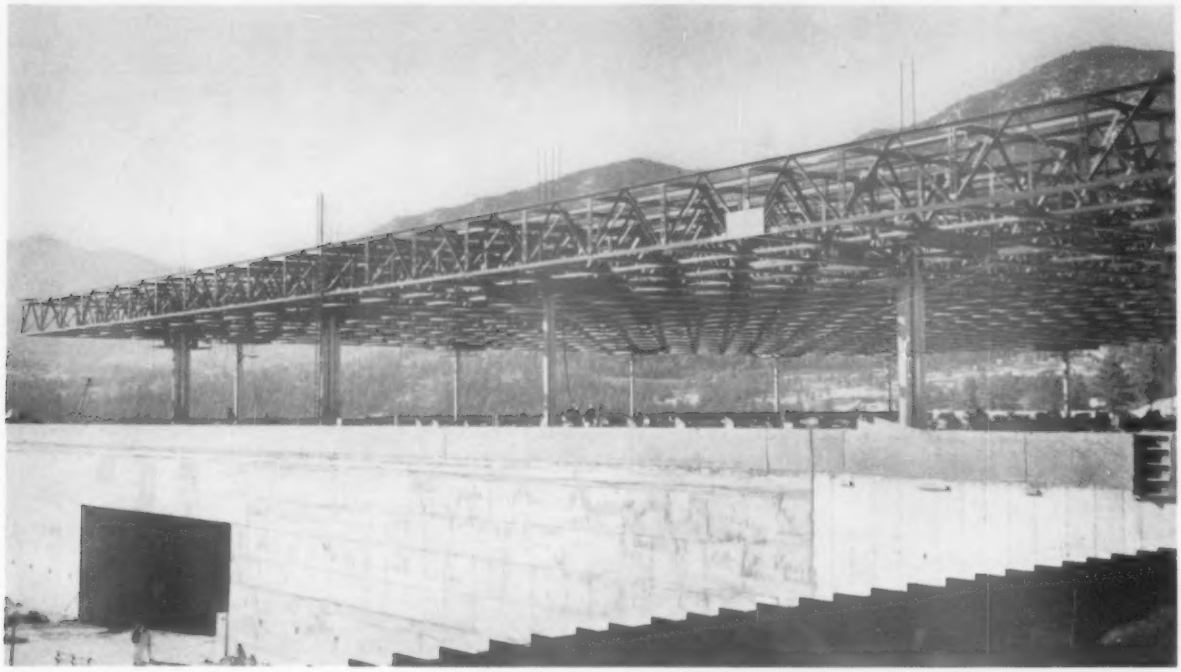


Fig. 1 View of structure after erection

ENGINEERING PROBLEMS OF AN ALL-WELDED TWO-WAY TRUSS SYSTEM

BY WAYNE TENG, JOHN A. SBAROUNIS AND MICHAEL P. GAUS

Design, fabrication and erection of all-welded truss system for roof of Cadet Dining Hall at Air Force Academy presents several novel and interesting problems

SYNOPSIS. The roof of the Cadet Dining Hall at the Air Force Academy, Colorado Springs, Colo., is a large span all-welded two-way truss system which covers an area 308 x 308 ft. The design, fabrication and erection presented several novel and interesting problems. Since this was an indeterminate structure of unusual dimensions, a careful design analysis was required. The welding details and procedure had to be such that continuity would be preserved in both directions without the introduction of undue residual stresses, accumulated shrinkage, etc. In order to facilitate the work, the contractor chose to assemble the structure on the ground and subsequently raise it to its proper elevation by the lift-slab method, adapted from concrete construction techniques. Field observations indicated that the construction procedures produced a finished structure which approximated very closely the idealized structure assumed in the design analysis.

Wayne Teng is assistant chief structural engineer, and **John A. Sbarounis** is senior structural designer at Skidmore, Owings & Merrill, Chicago, Ill. **Michael P. Gaus** is research associate in civil engineering, University of Illinois, Urbana, Ill., formerly senior structural designer, Skidmore, Owings & Merrill, Chicago, Ill.

Paper presented at AWS Annual Spring Meeting held in St. Louis, Mo., April 14–18, 1958.

Description of Structure

The Cadet Dining Hall is one of seven major buildings to be constructed in the academic area of the United States Air Force Academy at Colorado Springs, Colo. The roof structure of the dining hall is a two-way truss system covering an area of 308 x 308 ft. Sixteen steel columns, arranged four to a side and set in 21 ft 0 in. from the edge of the structure, support the entire roof. Thus an unobstructed interior span of 266 x 266 ft is provided.

The grid structure consists of 23 Warren trusses spaced at 14 ft 0 in. o.c. in each direction (Fig. 2). All connections, splices and intersections are welded to achieve continuity in both directions throughout the structure. The grid is symmetrical about the two

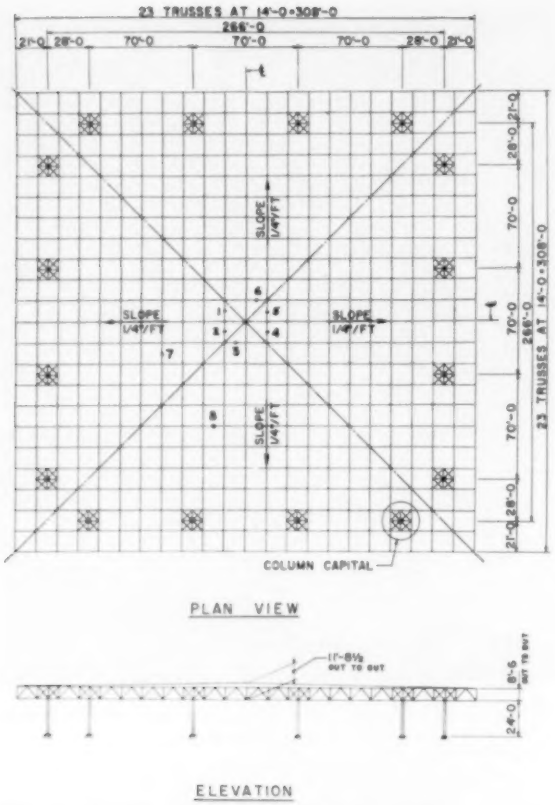


Fig. 2 Plan view and elevation of roof structure

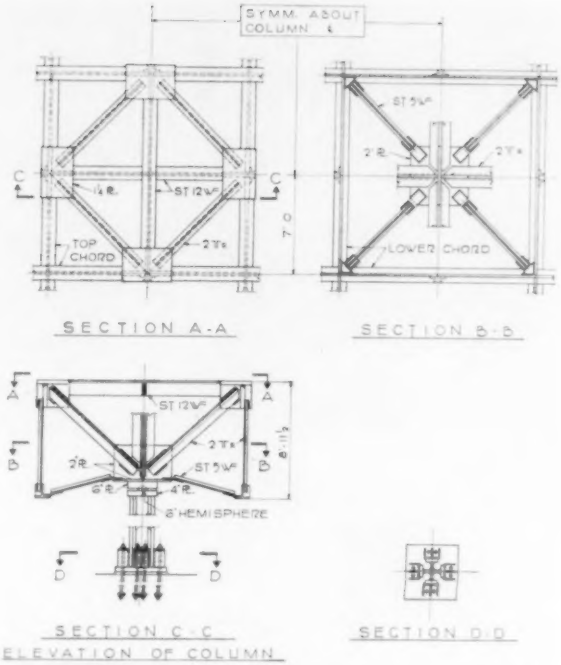


Fig. 3 Elevation of column and sections through column capital

centerlines and two diagonals. The trusses are 8 ft 6 in. deep along the four edges. A slope of $^1/_4$ in. per ft in four directions was introduced in the top chord for roof drainage and at the same time to increase the depth at the center to 11 ft $8^1/_2$ in. Thus the average depth to span ratio is $^1/_{27}$ and the maximum $^1/_{22}$. The main considerations in arriving at these proportions were appearance combined with reasonable deflection and economy.

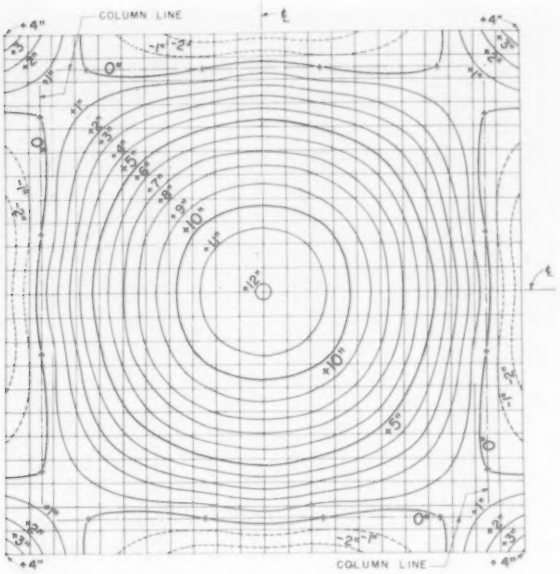
Load is transferred from the grid to the column by means of a framework hereinafter referred to as the column "capital." Figure 3 shows an elevation of the column and several sections through the capital. The top of each capital is attached to the grid at four points. A socket plate at the base of the capital rests on a 6-in. stainless-steel hemisphere which is affixed to the top of the column. The ball-and-socket joints permit free rotation of the grid and column capitals, without introducing bending in the columns. The lower ends of the steel columns are rigidly fixed to large subpiers or massive concrete columns. The ball-and-socket joints were waterproofed with 9-in. diam neoprene washers.

Design Analysis

Due to the high degree of redundancy and the lack of previous experience, the structure was analyzed by two different methods. It was felt that the use of the two different methods would eliminate any error inherent to either one and at the same time provide an independent check.

The first method used was a method of consistent deflections. This method may be outlined as follows: at each intersection of two trusses there is a joint load P equal to the uniform roof load multiplied by the tributary area, plus the weight of the trusses. If the loads at all the joints were divided equally between the intersecting trusses and the trusses were permitted to deflect as free bodies independently of each other under these loads, the deflections of the two intersecting trusses at every joint would be unequal. However, in the case of a grid, the two intersecting trusses deflect equally at every joint. In order to make the deflections equal, two unknown equal but opposite forces $\pm K_x$ are introduced at each joint. Therefore, the correct panel loads for the two trusses at each intersection are $(^1/_2 P + K_x)$ and $(^1/_2 P - K_x)$.

Considering each truss as a free body, the deflections of all the panel points can be expressed in terms of the known loads and the unknown forces. This may be done by means of visual work or any equivalent method. If the deflections of the two intersecting trusses at each joint are equated, a set of simultaneous equations is derived with the same number of unknowns as the number of joints in the grid. The number of equations is reduced drastically if the structure and loads are symmetrical as in the case of the dining hall. The unknown forces are obtained by solving the simultaneous equations. After the correct panel loads $(^1/_2 P \pm K_x)$ are found, the member stresses in the trusses are obtained. If the resulting member stresses do not match



NOTE: Deflections are for dead load plus maximum uniform live load. Positive deflections are downward. Specified camber is equal to deflections shown but of opposite sign.

Fig. 4 Camber diagram

the capacity of the assumed member sizes, new member sizes are selected and another analysis is performed. The preliminary work was reduced considerably by analyzing an equivalent coarse grid with a 42-ft truss spacing and by distributing the stresses to adjoining trusses, which had been omitted, in proportion to their stiffness. As the work progressed, more trusses were introduced in their true location; thus, the accuracy of the solution progressed in stages.

After a satisfactory solution was reached by the method of consistent deflections, the structure was analyzed by a second method. Since deflections due to shear are proportionally small, particularly for trusses of low depths to span ratios, the truss system was replaced by an equivalent flexural grid.

If an orthogonal anisotropic grid is referred to a cartesian set of coordinates X and Y, with the members running in the X and Y directions, the differential equation for the grid takes the form:

$$\frac{\partial^2}{\partial x^2}\left(EI_x \frac{d^2w}{dx^2}\right) + \frac{\partial^2}{\partial y^2}\left(EI_y \frac{d^2w}{dy^2}\right) = p(x, y)$$

where

E = modulus of elasticity.
I_x = moment of inertia in X direction.
I_y = moment of inertia in Y direction.
w = deflection at any point.
$p(x, y)$ = intensity of loading at any point.

A solution of this differential equation is possible through the application of the finite difference procedure, which reduces the problem to the solution of a system of linear simultaneous algebraic equations. When solved, the equations yield deflections at particular points. Moments, shears, reactions and member stresses for the trusses in the grid are obtained from these deflections. One equation is required for each point on the grid at which the deflection is to be found.

Due to the large number of simultaneous equations in both analyses, a digital computer was used in their solution. The two solutions checked adequately.

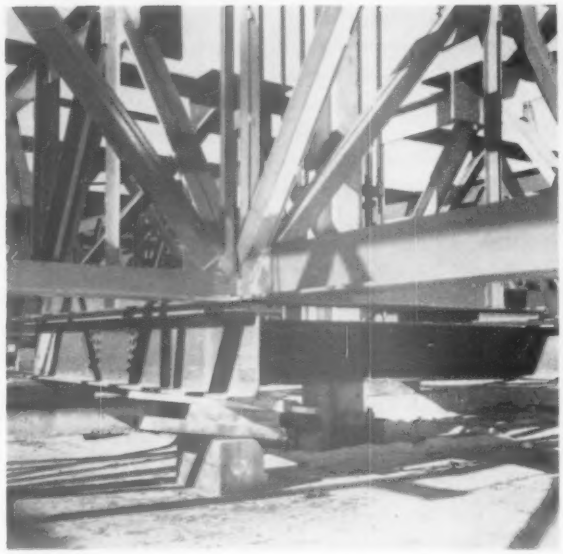


Fig. 5 View of a lifting frame and a lower panel joint

Column Design

In addition to the vertical load from the roof (dead plus live load) and wind thrust, two other significant factors affected the design of the columns. An assumed temperature variation of 100° F produced a horizontal displacement of over 1 in. at the top of the columns. The rotation of the grid at the supports introduced additional horizontal displacement.

The columns were rigidly fixed at their base; therefore, a compact section was indicated which would permit bending without overstress. The corner columns deflect almost equally in both directions; consequently, the section selected should have equal moments of inertia about both major axes. The cross section ultimately chosen has the shape of two intersecting I's. It meets all of the above requirements, is easy to fabricate and presents a slender uniform appearance. The external surfaces of the grid are insulated; thus, the temperature of the structure will not vary considerably from 70° F when the building is in service.

Welding Details

An all-welded structure was selected because of the several advantages associated with welded construction. Welded truss joints are compact; therefore, secondary stresses are kept to a minimum. The total weight of welded trusses is smaller than that of riveted or bolted trusses. This is a decided advantage in large spans. Continuity is more readily achieved with welded joints, especially in a grid system, where a number of

members intersect at each joint. Welded joints produced a flush surface on the upper chords; thus, a metal deck could be placed directly on them.

The welding details played an important role in the selection of the types of cross sections for the truss members. Structural tees were chosen for the truss chords and angles for the web members. The tee sections eliminated the use of gusset plates in the majority of the joints. In addition, tees are easily spliced by butt welding whether or not the two members have the same proportions. It was also believed that tees were more suitable for connections in this case, since several horizontal and diagonal members converge at one joint (Fig. 5).

As shown in Fig. 7, some trusses were fabricated in longer lengths in the shop ("through trusses") while others were only one bay (14 ft) long and had to be fitted and welded in the field ("interconnecting trusses"). It was left to the discretion of the contractor as to the length and location of the "through" and "interconnecting trusses." However, it was required that the flange of the tee in a "through truss" should be at least as thick as the flanges of the abutting "interconnecting trusses." Figure 6 shows typical welding details of the "through trusses" and the "interconnecting trusses."

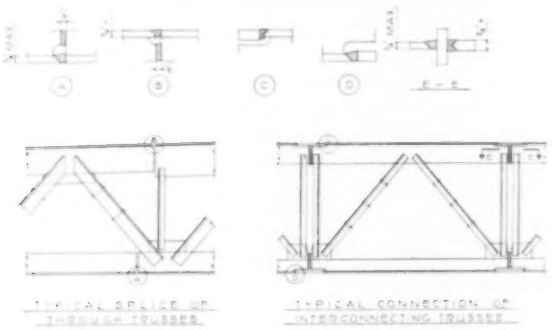


Fig. 6 Typical truss details and connections

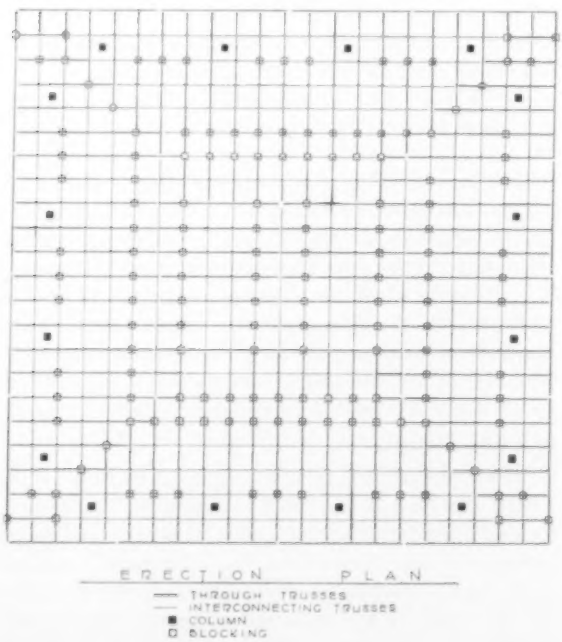


Fig. 7 Erection plan

Among the most critical considerations affecting the welding details were elimination of locked-in stresses and reduction to a minimum of accumulated shrinkage due to welding. The fabrication and erection procedure was formulated with these in mind. The contractor chose to assemble and fabricate the entire structure at grade and raise it to the final elevation by the lift-slab method.

Prior to welding, north-south and east-west base lines were established through the center of the structure. The trusses were placed at their proper distance plus approximately $^1/_8$ in. from the base lines and at the correct camber. Welding was started at the center of the structure. Thus adjustment for shrinkage was made possible as welding proceeded outwards. The actual lengths of the various truss segments and the method of support during the assembly at grade are shown in Fig. 7. Figure 8 is a view through the structure showing the temporary blocking of the grid and typical welded connections.

All sections and parts were rolled from Type II steel (ASTM Designation A-373) including the column and base plates. A total of 1150 tons of steel and 11,500 lb of welding wire were used on the grid structure. A large number of welds were radiographed.

Erection Procedure

The erection of the grid structure was made in three stages: (1) assembly of trusses at grade and erection of columns; (2) raising the grid structure by the lift-slab method; and (3) installation of column capitals.

All columns were erected free-standing at the same time as the grid trusses were assembled and welded on the ground. A 10-in. wide flange section was bolted to the top of each column to serve as a seat for the hydraulic lifting jacks. Calculations indicated that the center columns take approximately twice as much load as the corner columns. Two lifting jacks were therefore seated on each of the center columns and one on each corner column.

The standard lift-slab method had to be modified slightly in raising the grid. The lifting force was applied to a frame of standard steel shapes through two threaded high-strength steel rods. This frame in turn picked up the grid at four panel points around each column (Fig. 5). The jacks have a 3-in. travel. At the end of each 3-in. lift, two nuts located on the threaded lifting rods were brought to bear on a subframe attached to the jacks while the piston was returned to its initial position. This operation was repeated until the total desired lift was obtained through a series of 3-in. increments. All the jacks were operated from two control consoles. No one jack was permitted

Fig. 8 View through structure prior to lifting

to lift more than $\frac{1}{4}$ in. ahead or behind the other jacks at any time during the lifting operation.

The final lift brought the grid to a height 2 in. above its final elevation. Two timber posts were lashed to each steel column and a pair of hydraulic jacks were placed on the posts to support the grid. The lifting jacks were then removed. Subsequently the column capitals were welded and the grid was lowered to its final position. Some difficulty was anticipated due to thermal contraction since the structure was fabricated for an assumed temperature of 70° F and erected during cold weather. The contractor was therefore required to pull the columns inward to fit the ball-and-socket detail. It is believed that there will be very little bending in the columns during the normal operation of the building at 70° F since the columns will return to their design location and remain plumb. The erection procedure and all its details were worked out by the fabricator-erector, American Bridge Division of U. S. Steel Corp.

Camber and Stress Measurements

Figure 4 shows the specified camber based on the calculated deflections under total load. The elevation of the lower panel points was checked by precision survey immediately before and after the structure was lifted. A plot of the results indicated that the specified camber was correctly applied and that the maximum deflection under the dead load of the steel was $5\frac{1}{2}$ in. Figure 9 shows the camber and deflected line of a center truss and the point of maximum deflection.

In addition to the deflection measurements, a limited number of stress measurements was made by means of a Whittemore gage at selected points on the lower chord (Fig. 2). Readings were taken in four locations at each point, one on each side of the stem and the flanges of the tee. The average axial stresses for the various points are tabulated below:

Points	*Average axial stress, ksi*
1	6.3
2	7.0
3	7.0
4	7.3
5	6.4
6	7.3
7	6.8
8	5.5

The weight of steel constitutes about 43% of the total design load at the center of the roof, 33% near the quarter points and 12% along the edges. No exact calculations have been made as of now to determine the exact stresses and deflections of the structure under its own weight, but, a comparison of these load ratios and the deflection and stress measurements indicate that the behavior of the truss-grid can be predicted by the design analysis. The design assumptions and the construction procedure were proven satisfactory.

Acknowledgment

The construction of the U. S. Air Force Academy is under the supervision of the Air Force Academy Construction Agency, in Colorado Springs, Colo. The architectural and engineering design was done in the Chicago office of Skidmore, Owings & Merrill, J. O. Merrill, partner in charge, Walter Netsch, Jr., chief of design, Jack Train, chief of production, and Andrew J. Brown, chief structural engineer.

Messrs. C. L. Tyler and E. A. Merrill are general manager and director of engineering for the Colorado Springs office of Skidmore, Owings & Merrill with L. B. Carnahan acting as resident engineer. The photographs were supplied by H. La Plant.

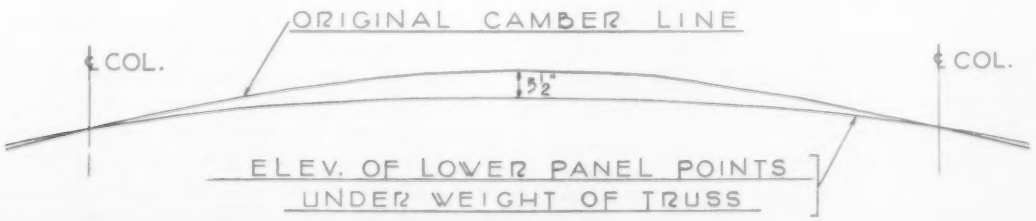


Fig. 9 Camber and deflection lines of the center trusses

Fig. 1 Rocker-arm spot welder—9200 lb force—78-in. throat—dry-disk rectifier type used in spot welding Inconel "X" in range of 0.093 to 0.188 in. thickness

SPOT WELDING OF INCONEL "X" IN THICKNESS RANGE OF 0.032 TO 0.188 IN.

Authors indicate that if welding variables are controlled, there are a number of schedules that will produce satisfactory welds for any specific thickness of Inconel "X"

BY JEAN HARRIS, M. D. BELLWARE AND J. J. RILEY

ABSTRACT. This article outlines recommended welding schedules for spot welding Inconel "X" sheets of 0.032-, 0.062-, 0.093-, 0.125-, 0.143-, 0.156- and 0.188-in. thicknesses. The weld quality meets the requirements of Military Specification MIL-W-6858A. The work was performed on several sizes of welding machines which includes the three-phase dry-disk rectifier type and single-phase type. The basic approach was to formulate two sets of schedules, one using high welding pressure and the other lower pressure.

The welding technique was developed as required to produce sound welds for each condition. The interdependent variables are discussed with respect to their influence on weld strength and weld soundness.

The results indicate that satisfactory welds can be made on either three-phase or single-phase equipment. It is not necessary to use high values of weld force if the geometric shape of the product makes adequate tooling design impossible.

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It should not be inferred that Inconel "X" can be successfully spot welded without carefully controlled welding conditions. Yet, if the welding variables are controlled, there is a number of schedules that will produce satisfactory welds for any specific thickness.

Introduction

The use of heat-resistant alloys of high nickel content has been steadily increasing. Published information[1–3] on spot-welding technique for Inconel "X," nickel-chromium-iron alloy, covers the lower range of thicknesses to a maximum of 0.062 in. The basic spot-welding technique consists of high electrode force and short weld time. This approach is satisfactory in the aforementioned thickness range. An attempt to extend this technique to 0.125-in. thickness Inconel "X" results in welds with a definite degree of porosity regardless of the electrode force. However, the welds are not cracked and are acceptable for many applications.

It was apparent that a new welding technique had to be devised if porosity were to be eliminated. The technique consisted of a dual pressure and a dual current cycle. The weld was formed during the application of *weld force* and the defects prevented by *forge force* in the temper current period. The weld was formed during the flow time of the welding current and was kept in a plastic condition by a temper current after a cooling (quench) period. The porosity, in most instances, was decreased to an undetectable point in X-ray examination. The porosity was well within the limits of MIL-W-6858A.

This technique is illustrated diagrammatically in Fig. 2, which also defines the terms.

The weld quality was established to meet the MIL-W-6858A requirements. These basically are:

1. A fusion zone which is practically porosity-free and contains no cracks.
2. Sheet separation less than 10% of the average thickness of the sheets.
3. Fusion-zone penetration 20 to 90% of the total thickness of the sheets.
4. No external defects such as surface flashes, cracks, expulsion of metal between sheets, etc.
5. Porosity limitation to within 10% of weld area, 15% of weld diameter and less than 15% of projected weld boundary.
6. Surface indentation was limited to 10% or 0.005 in., whichever is greater, of the thickness of the sheet in which the indentation occurs.

The spot-weld tensile-shear strength was established as 10% above the minimum average of MIL-W-6858A. As no values are given beyond 0.125-in. thickness in this specification, the requirement beyond 0.125-in. thickness was estimated.

Material

The material used was Inconel "X" strips cut from a single sheet of the material. The sheets were supplied in the annealed condition. Table 1 lists the chemical analyses and mechanical properties of Inconel "X." The coupon sizes used in the welding were:

Thickness	*Width*	*Length*
0.031	3/4	3
0.062	1	4
0.093	1 1/4	5
0.125	1 1/2	6
0.140	1 1/2	6
0.156	2	6
0.188	2	6

Equipment

The equipment used incorporated all the latest features available in electronic-control design. Rather than struggle to develop welding schedules using a simple weld cycle, the emphasis was to develop schedules that could readily be applied to production processing even though more complex welding controls were required.

The single-phase control had features of up-and-down slope control, forge delay and chill-and-temper sequence

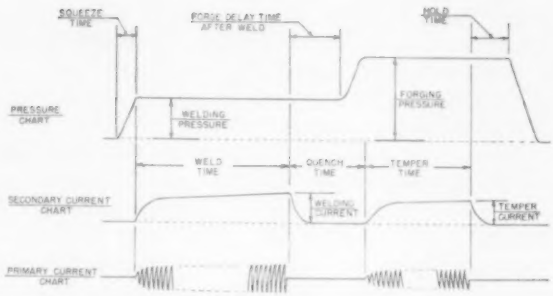


Fig. 2 Spot-welding technique for Inconel "X"

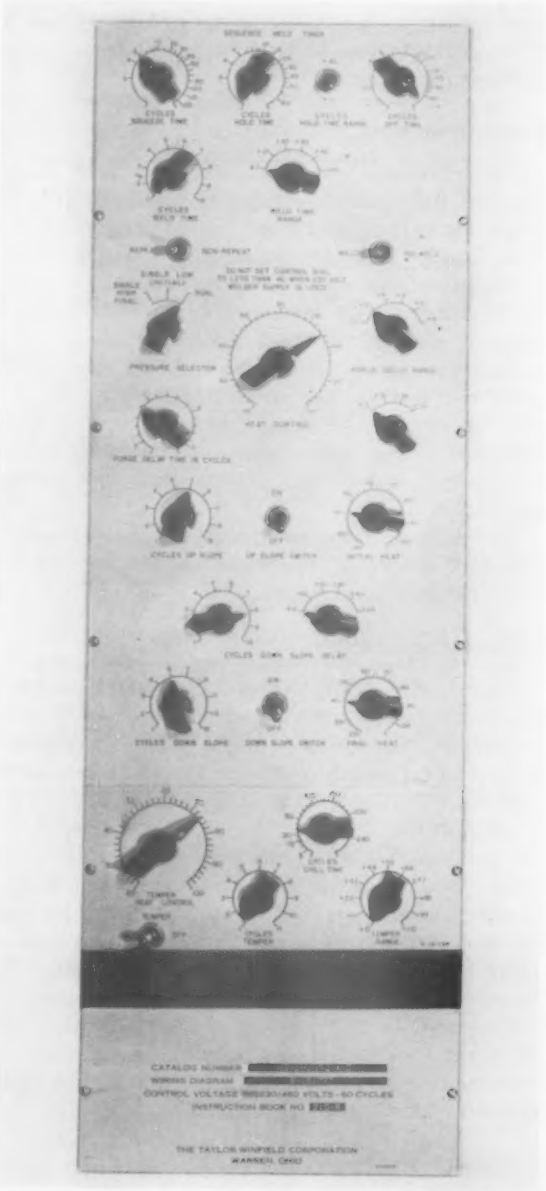


Fig. 3 Adjustment panel of single-phase spot-welding control with up-and-down slope-control forge time and with quench and temper

as is evident from the adjustment dial, Fig. 3. This control was used with a laboratory press welder capable of exerting 18,000-lb force. The combination was used to weld the heavier thickness (0.093 to 0.188 in.), employing single-phase power.

The welding using three-phase power was performed on two sizes of equipment. One was an RWMA Size 2 press welder equipped with dual force sequence and a dry-disk rectifier power pack. The other machine, a rocker-arm type, and control were especially designed to spot weld Inconel "X." The machine is shown in Fig. 1. It has a 78-in. throat and is capable of exerting a maximum of 9200 lb in a dual force sequence.

The three-phase control designed for use with this equipment provided practically every known weld-current pattern sequence for three-phase equipment. The number of possibilities is apparent from the adjustment dials, Fig. 4.

Instrumentation

Contact-resistance measurements were made using a modified Kelvin double-bridge circuit, at 24-amp d-c measuring current, and a mechanical press. An electrode force of 1000 lb was used with $^5/_8$-in. diam Class II electrodes faced with 3-in. radius dome.

The current and pressure timing intervals were measured using a direct inking oscillograph. Current magnitudes were checked using a d-c shunt on the three-phase equipment and a current transformer inserted in the primary of the welding transformer on single-phase equipment. The magnitudes were measured on the oscillograph and cross-checked using pointer-stop instruments.

The electrode force was provided by a frictionless, calibrated airlock on all equipment and was checked with a mechanical force gage.

Surface Preparation

When spot welding Inconel "X," careful consideration should be given to the surface condition. A tenacious oxide may be present due to prior heat treatment or due to long periods of storage, especially in some industrial atmospheres. The oxide is difficult, if not impossible, to remove by rubbing with steel wool, revolving stainless-steel wire brush, or rubbing with emery cloth. If cleaning must be by mechanical means, grinding is recommended. However, it is usually more practical to clean chemically with a solution such as shown in Fig. 5. This method was used to reduce the "as-received" contact resistance of 150 to 375 microhms to that used in spot welding of 25 to 75 microhms. The lower surface resistance avoided the expulsion between electrode and sheet and between sheets which occurred when the surface was not cleaned.

Investigation Procedure

Sufficient material was not available to investigate carefully the effect of each welding variable in each thickness on weld quality. Past experience of the au-

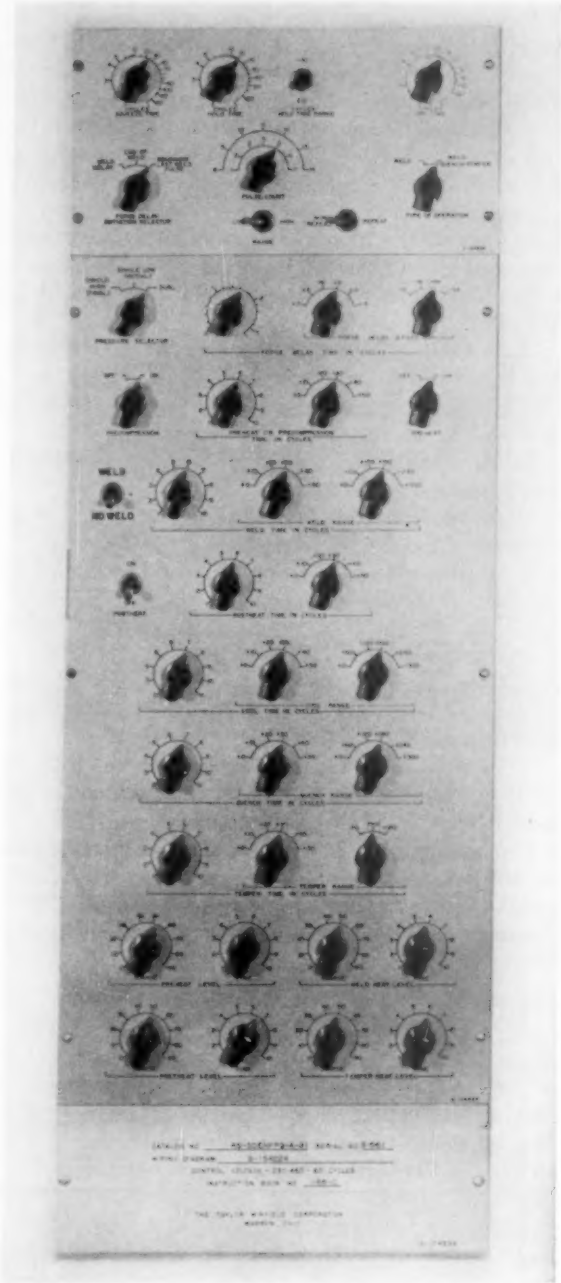


Fig. 4 Adjustment panel of three-phase spot-welding control with preheat, weld, postheat, quench and temper, forge time, multiple and single-impulse weld-current pulses; and pre-compression

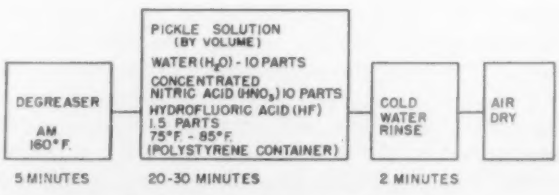


Fig. 5 Chemical cleaning of Inconel "X"

Table 1—Chemical Analysis and Mechanical Properties of Inconel "X"

Heat No.	Thickness	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Ta + Cb
HT 7662X	0.031	0.05	0.62	6.82	0.007	0.32	0.03	73.03	15.15	0.73	2.49	0.73
HT 7247X	0.062	0.05	0.62	6.98	0.007	0.38	0.05	72.60	15.16	0.81	2.45	0.87
HT 7466X	0.093	0.05	0.82	6.92	0.007	0.36	0.03	72.56	14.96	0.77	2.63	0.87
HT 4927X	0.125	0.05	0.73	6.94	0.007	0.34	0.06	72.86	14.81	0.84	2.44	0.90
HT 7664X	0.140	0.04	0.58	6.55	0.007	0.29	0.04	73.26	15.29	0.78	2.43	0.71
Typical analysis		0.05	0.50	7.00	0.005	0.40	0.05	73.00	15.00	0.75	2.50	0.90

Annealed mechanical properties

Heat No.	Annealed thickness, in.	Rockwell hardness	Yield strength, psi	Tensile strength, psi	Elongation, %	Average grain diameter, in.
HT 7662X	0.031	30T67.0	44,000	106,500	58.0	0.0022
HT 7247X	0.062	R_B 86.5	48,500	110,000	51.0	0.0016
HT 7466X	0.093	R_B 84.5	46,000	111,000	52.0	0.0018
HT 4927X	0.125	R_B 86.5	49,000	109,000	51.0	0.0025
HT 7664X	0.140	R_B 88.5	50,000	114,000	52.5	0.0018

NOTE: Detailed data were not available on 0.156- and 0.118-in. thicknesses.

Table 2—Preliminary Weld Schedules of Inconel "X"

Three-Phase, Dry-Disk Rectifier-Type Welder

Schedule No.	Material thickness, in.	Electrode force, lb		Time settings, cycles					Secondary current, amp		
		Weld	Forge	Weld	Quench	Temper	Forge*	Hold	Weld	Temper	Temperature/weld
1	0.143	3500	9200	100	None	None	40	120	11,300	None	...
2	0.143	4500	7500	100	5	150	20	120	11,350	8,540	0.75
3	0.143	3500	6000	100	5	150	20	120	11,350	9,100	0.80
4	0.143	4500	8000	80	5	99	20	120	12,500	9,300	0.745
5	0.125	3000	5100	80	5	135	18	120	10,680	8,960	0.84
6	0.125	4100	7500	71	5	96	18	120	10,820	8,110	0.81
7	0.093	2200	4800	67	5	99	13	120	8,510	7,380	0.868
8	0.093	3300	6700	54	5	73	13	120	10,220	8,650	0.845
9	0.156	3750	6350	110	20	170	22	240	11,250	8,750	0.776
10	0.156	4850	9000	80	5	120	24	120	12,600	9,340	0.746
11	0.188	4700	7150	139	30	180	27	240	13,250	9,760	0.716
12	0.188	6100	9200	103	30	146	27	240	15,000	10,480	0.70
13	0.062	1410	2900	43	0	68	8	60	6,630	4,600	0.694
14	0.062	2500	4500	37	0	46	8	50	8,000	5,500	0.687
15	0.032	850	1850	22	0	32	3	60	5,500	4,100	0.748
16	0.032	1750	2800	13	0	13	3	60	6,630	4,600	0.695

* Measured after weld-current flow.
Electrodes RWMA Class II—8-in. radius dome 0.188-0.093.
RWMA Class III—6-in. radius dome 0.062-0.032.

Schedule No.	Material thickness, in.	Weld properties: Average tensile shear, lb	Weld properties: Weld diameter, in.	Weld properties: % Penetration	Comments
1	0.143	...	...	...	...
2	0.143	7,875	...	...	No defects X-ray
3	0.143	8,766	0.420	60.5	No defects X-ray
4	0.143	8,366	0.385	52.8	No defects X-ray
5	0.125	7,593	0.368	57.6	Bad defects X-ray
6	0.125	8,240	0.379	54.2	No defects X-ray
7	0.093	5,603	0.345	47.5	No defects X-ray
8	0.093	5,832	0.327	52.8	No defects X-ray
9	0.156	10,240	0.423	64.1	No defects X-ray
10	0.156	10,236	0.436	63.8	Minute defects X-ray
11	0.188	10,280	0.445	63.0	No defects X-ray
12	0.188	11,567	0.456	63.5	No defects X-ray
13	0.062	3,370	0.28	43.0	No defects X-ray
14	0.062	3,242	0.27	63.0	No defects X-ray
15	0.032	1,155	0.175	45.0	No defects X-ray
16	0.032	1,154	0.141	45.0	No defects X-ray

Table 3

Basis Schedule No. 2 Table 2 Welding 0.143-in. Thickness
Welding Current Constant at 11350 amp—82% Heat Control

—Temper current*— Heat control	Amp	Ratio temper to weld current	Results from X-ray examination
0	0	...	Large elongated defect
50	6870	0.625	Smaller round defect
55	7390	0.725	Minute round defect
62	8540	0.75	No defects—Schedule No. 2 value
65	8750	0.85	No defects
70	9700	0.94	Minute round defect

* Temper current ranges from 70 to 85% of weld current in schedules shown in Table 2.

Table 4—Effect of Temper Time on Weld Porosity

Basis Schedules from Table 2

Schedule No.	Thickness, in.	Temper time schedule	Minimum temper time at which defects appear, cycles
8	0.093	73	20—minute defect
6	0.125	96	70—minute defect
4	0.143	99	70—minute defect
10	0.156	120	100—minute defect
12	0.188	146	120—minute defect

NOTE: Longer temper times have no noticeable effect on weld porosity.

thors had to be relied on to establish welding schedules quickly. The effects of each variable could be determined by varying only one on a specific thickness, another on a different thickness, etc. In this manner the welding schedules were devised and the effects of the variables determined.

Two equal thicknesses of 0.143-in. stock were selected as the first gage to be welded. A force of 9200 lb, the limit of the equipment in Fig. 1, was used in a dual pressure sequence. A low initial pressure was used to establish the desired penetration, the final pressure to minimize weld defects. The welding variables are indicated in Schedule No. 1 in Table 2. The welds were free of cracks but had porosity within the limits of MIL-W-6858A.

Previous experience on stainless steels had indicated that much less porosity resulted if, after weld-current flow, the current be lowered but kept flowing while the weld was subjected to the final or high value of force.

This technique was altered slightly to give a cooling period between *weld current* and the low current following it, referred to as *temper current*. Using only 7500-lb force resulted in sounder welds than the 9200 lb used in Schedule No. 1. The welding data are indicated as Schedule No. 2 in Table 2. The effect of varying the temper current is shown in Table 3.

The welding variables were again altered to produce sound welds at 6000-lb force. This is Schedule No. 3 in Table 2.

Table 5—Recommended Schedules for Inconel "X"

Three-Phase Dry-Disk Rectifier Equipment

Material thickness, in.	Electrode force, lb		—Time settings, cycles (60 cps)—				Secondary current		Average tensile weld		Minimum weld spacing, in.†
	Weld	Forge	Weld	Quench	Temper	Forge*	Weld	Temper	Shear	Diameter	
0.032	1700	2800	13	0	13	4	6,550	4,400	1,200	0.160	0.75
0.032	850	1850	22	0	32	5	5,500	4,100	1,160	0.170	0.75
0.062	2600	4500	35	2	46	8	8,300	5,650	3,600	0.270	1.25
0.062	1450	2900	44	2	67	9	7,100	5,350	3,400	0.280	1.25
0.093	3500	6200	55	7	73	14	10,000	7,000	6,000	0.327	1.6
0.093	2200	3950	65	7	100	14	8,750	6,700	5,550	0.345	1.6
0.125	4300	7700	73	13	99	18	11,750	8,350	8,140	0.379	2.1
0.125	3000	5000	78	13	132	19	10,350	8,000	7,550	0.368	2.1
0.143	4650	8400	83	17	112	21	12,700	9,050	9,200	0.385	2.4
0.143	3500	5650	101	17	150	20	11,200	8,650	8,500	0.420	2.4
0.156	4950	8800	89	21	121	24	13,600	9,700	10,100	0.423	2.7
0.156	3950	6220	113	21	165	23	12,000	9,300	9,500	0.436	2.7
0.188	5600	9500	100	30	145	28	14,700	10,450	11,300	0.456	3.0
0.188	4650	7150	133	30	187	26	13,050	10,100	10,650	0.445	3.0
					Single-phase schedules						
0.093	3300	6600	54	5	73	14	9,800	7,800	5,100	0.31	1.6
0.093	2200	4700	66	5	92	13	9,200	7,300	4,900	0.30	1.6
0.125	4100	7550	70	13	97	18	10,900	8,500	7,700	0.37	2.1
0.125	3050	5600	90	12	130	18	9,700	7,500	7,700	0.39	2.1
0.143	4600	8000	79	17	110	20	10,700	8,300	8,300	0.41	2.4
0.143	3500	6100	102	16	152	20	9,300	7,200	8,300	0.40	2.4

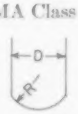
On single-phase a-c schedules a 5-cycle up-slope time was used as part of the weld time. The initial current was 30% of the welding maximum current.

* Forge delay measured after welding current flow (Fig. 2).

† Spacing centerline to centerline of weld nuggets—spacings above this value require no increase in welding current to compensate for shunting of previous welds.

1. Material should be chemically cleaned.
2. Data based on welding two pieces of equal thickness.
3. Minimum overlap is 3 times the weld diameter or one-half the minimum weld spacing, whichever is larger.

Electrodes RWMA Class 3



0.032, R = 6 in., D = 0.88
0.064 – 0.125, R = 8 in., D = 0.88
0.143 – 0.188, R = 8 in., D = 1.5

A further attempt to reduce the weld time required that the electrode force be raised to 8000 lb, Schedule No. 4 in Table 2.

The tensile-shear value shown is the average of at least 20 welds.

The aforementioned procedure was used to establish two sets of welding conditions for 0.125-in. thickness, referred to as Schedules 5 and 6 in Table 2. These schedules did not produce sound welds. Both schedules produced welds with porosity. In determining these preliminary Schedules, about 5 welds would be made and a check on shear strength and internal porosity made. If these looked satisfactory, another 15 welds were made. In schedule No. 5, the first three welds had an average shear strength of 6810 lb. The other 15 welds had an average shear of 7593 lb. The weld size increased and, as it did, the defects appeared. The same thing occurred on Schedule No. 6 in which the first 5 welds had a strength of 6700 lb. It was later determined that the level of welding current had the principal effect on the size of the weld.

Using the above sets of data, Schedules No. 7 and 8, Table 2, were determined for 0.093-in. thickness.

By extrapolating the above data, tentative schedules were outlined for 0.156- and 0.188-in. thicknesses.

Schedules No. 9 and 10 in Table 2 apply to 0.156-in. thickness, but are the results of considerable manipulation of the previously extrapolated data. The effect of some of the minor variables on weld quality became evident.

Schedule No. 9 had minute defects. It was later determined that increasing the quench time to 20 cycles eliminated these defects.

Determination of Weld Schedule No. 10, Table 2, 0.156-in. Thickness

As an example of the influence of minor variables, the procedure used in forming this schedule will be explained.

1. *Effect of Hold Time*—Numerous defects were present in the spot welds using 120-cycle *hold time*. The weld had the spongy appearance of not cooling under pressure. The hold time was increased to 240 cycles and the major portion of the spongy appearance disappeared. However, there was some porosity left. Obviously another variable was partly responsible.

2. *Effect of Quench Time*—The use of the *quench time* variable was to allow the weld to cool and solidify partially. After the weld had reached this point, the weld cooling was again delayed by applying temper current. The forge force was applied in the temper period to hamper formation of defects. If the quench time is not long enough, the defects will not be eliminated. The weld is too hot and has not shrunk sufficiently to allow the processing during the temper-current flow period and hold time to be effective.

When small adjustments of the other variables did not eliminate the defects, the quench time was progressively increased from 5 to 30 cycles. The range from 20 to 30 cycles seemed most insensitive. Increasing the quench time to 20 cycles gave a wider range to the other variables such as temper current and temper time.

The minute defects shown in Schedule No. 9 were eliminated by increasing the quench time to 20 cycles

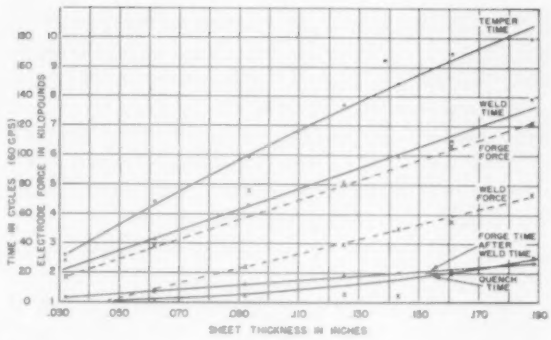


Fig. 6 Welding variables, low-pressure schedule—dry-disk rectifier—variables of weld and forge force, forge, temper weld and quench times vs. sheet thickness (see Fig. 7 for remainder of variables)

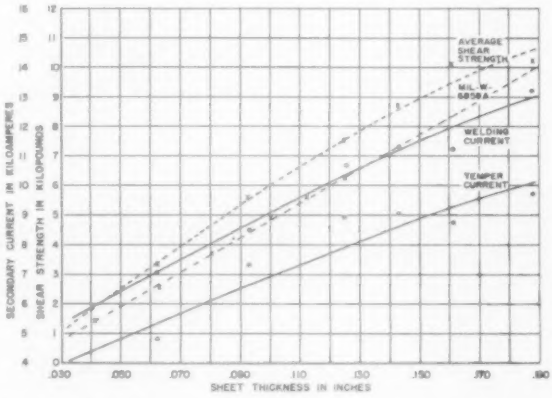


Fig. 7 Welding variables—low-pressure schedule—dry-disk rectifier—variables of weld and temper current, shear strength vs. sheet thickness (see Fig. 6 for remainder of variables)

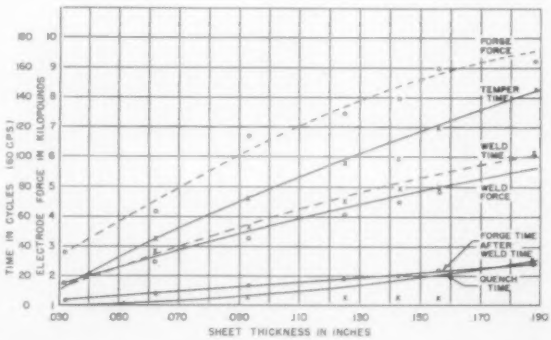


Fig. 8 Welding variables—high-pressure schedule—dry-disk rectifier—variables of weld and forge force, forge, temper, weld and quench times vs. sheet thickness (see Fig. 9 for remainder of variables)

from the 5 cycles indicated. Schedules No. 11 and No. 12, Table 2, on 0.188-in. thickness were determined after Numbers 9 and 10. These were rapidly made after the quench time was extended to 30 cycles.

3. *Effect of Temper Time*—To determine the sensitivity of temper time, it was progressively reduced in the schedules from Table 2: 4(0.143 in.), 6(0.125 in.), 8(0.093 in.), 10(0.156 in.) and 12(0.188 in.).

The minimum times at which defects appear are shown in Table 4.

The work progressed by welding 0.062-in. thickness indicated as Schedules 13 and 14 in Table 2. The quench time was reduced to zero for this thickness.

The extension of the work into the 0.032-in. thickness range gave a satisfactory high-pressure schedule, No. 15 in Table 2. The low-pressure schedule became a problem if the forge pressure was held to 1400 lb maximum. This was determined by extending the force curve from thicker to thinner thicknesses. Schedule No. 16 was developed at 1820-lb force maximum. This schedule did give satisfactory results.

This force is not "low" for this thickness, other schedules[1–3] giving different techniques use about the same value. It is questionable if the complex technique discussed in this paper is necessary on thin gages.

Recommended Schedules—Three-Phase Dry-Disk Rectifier. The data in Table 2 are plotted in a series of curves, Figs. 6–9. From these curves, Table 5 was made.

This table gives the recommended welding variables for spot welding equal thicknesses on three-phase dry-disk rectifier equipment.

Recommended Schedules—Single-Phase Equipment. Part of spot-welding program was duplicated on single-phase equipment. The welding variables are plotted in Figs. 10 and 11. From this series of curves the data were tabulated in Table 5. A 5-cycle up-slope time was used to simulate the slowly rising current wavefront which is inherent in three-phase equipment.

Metallurgical Characteristics and Abnormalities. Welds from each thickness of material were cross sectioned and given a thorough metallographic examination. In all cases the examinations indicated that a relatively high degree of soundness had been obtained. A typical cross section is shown in Fig. 12. Many of the welds etched darker near the center of the nugget, indicating a tendency toward dendritic segregation as shown in Fig. 13. This segregation is known in the foundry trade as "coring" and is not particularly detrimental. There was also a slight amount of sponginess found near the center of some of the welds, but the amount was well within recognized acceptable limits. Neither the segregation nor the sponginess was consid-

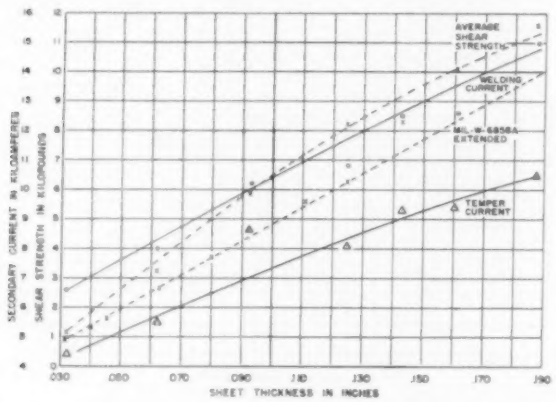


Fig. 9 Welding variables—high-pressure schedule—dry-disk rectifier—variables of weld and temper currents, shear strength vs. sheet thickness (see Fig. 8 for remainder of variables)

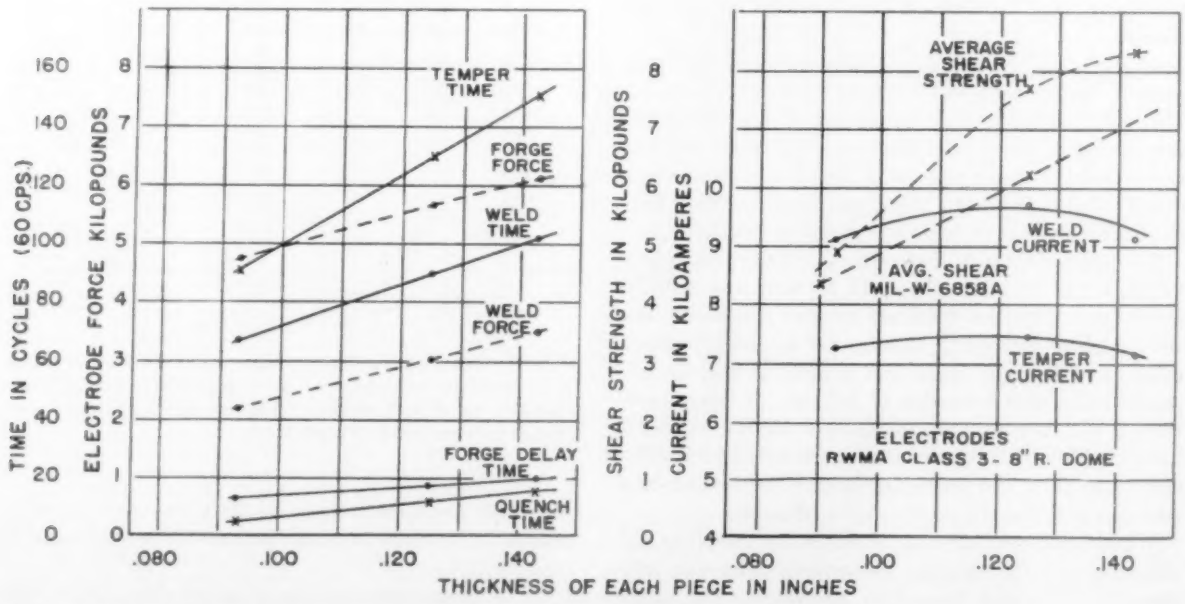


Fig. 10 Welding variables—low-pressure schedules, single-phase ac

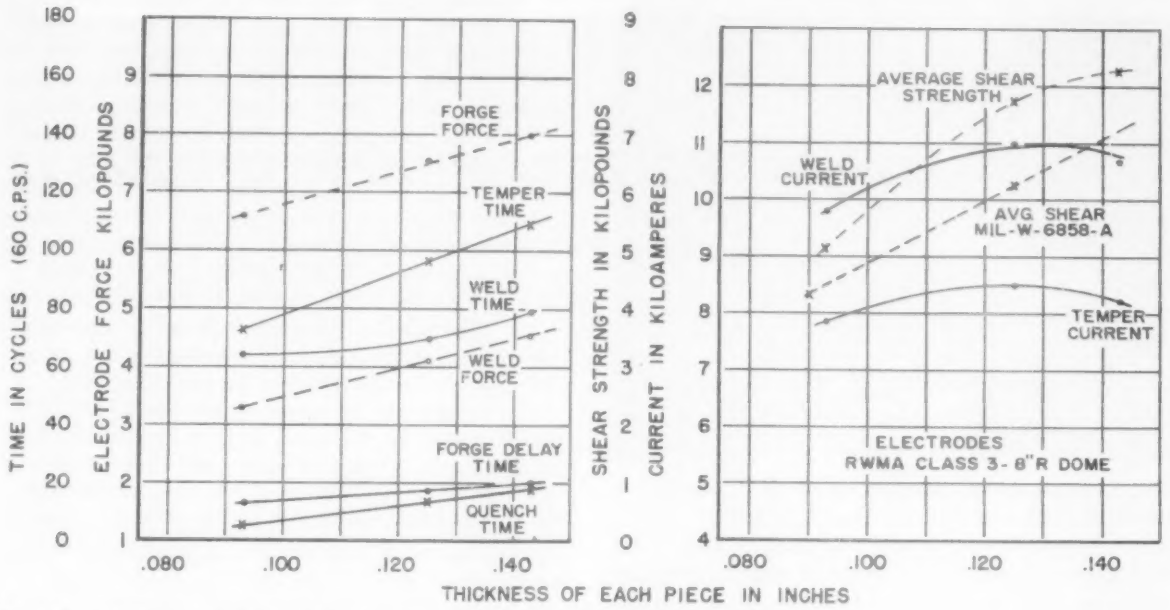


Fig. 11 Welding variables—high-pressure schedules, single-phase ac

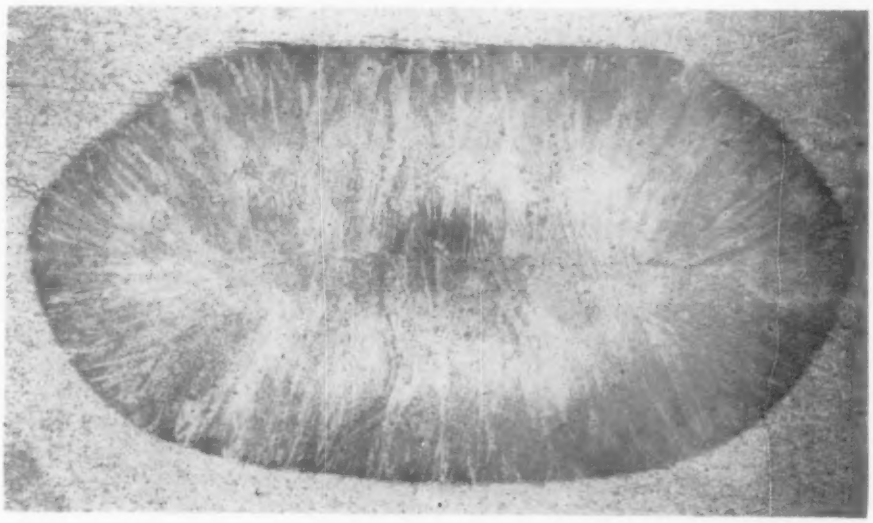


Fig. 12 Typical spot weld in Inconel "X" sheet. Specimen shown is 0.188-in. material. Glyceregia etch. X 10

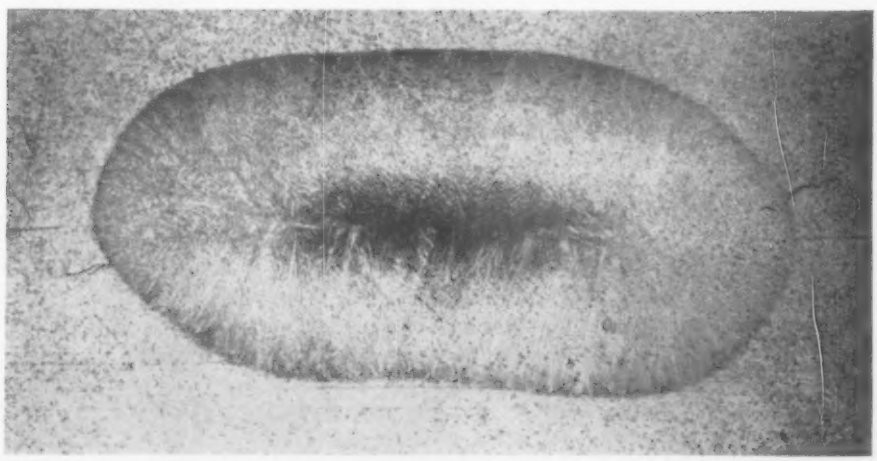


Fig. 13 Spot weld showing dendritic segregation near center of weld. This effect is not considered to be harmful. Glyceregia etch, X 10.

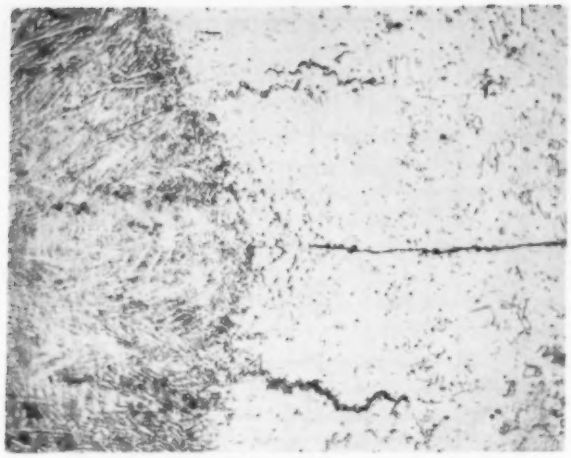


Fig. 14 Intergranular "fingers" of dendritic material in Inconel "X" adjacent to spot weld. Glyceregia etch, X 50

ered harmful enough to warrant any special consideration.

A different type of phenomenon which has also been referred to as coring,[4] was found in all of the specimens examined. It occurs in the area adjacent to the weld and can be seen in Fig. 14 as "fingers" of dendritic material extending outward from the weld nugget. This phenomenon has frequently been observed in other high-nickel alloys as well as Inconel "X." At low magnification, these areas sometimes appear to be cracks but higher magnification shows the fingers to be completely filled with sound metal.

The reason for the formation of this dendritic material is not known, but in no case in our experience has there ever been a failure that could be attributed to any weakness in this material. In fact, similar areas in other high-nickel alloys have shown a tendency to arrest fatigue cracks that have started at the notch between the two sheets of metal.

Conclusions

1. The spot welding of Inconel "X" to MIL-W-6858A can be accomplished by using the selection of welding variables tabulated in Table 5. The welds are porosity-free in X-ray examination.

2. The spot welding can be successfully accomplished using either three-phase dry-disk rectifier or single-phase equipment.

3. The oxide coating should be removed from Inconel "X" by using the chemical cleaning (or equivalent) method outlined in this report.

4. Inconel "X" can be spot welded at various pressure levels and result in sound welds, provided the technique of using a quench period followed by a temper period is used. Electrode force, regardless of magnitude, will not in itself eliminate defects in gages above 0.093-in thickness.

5. Porosity in the welds was definitely associated with the nugget size or shear strength. It is advisable to limit the shear strength to within 10% above the average values in MIL-W-6858A. It is difficult to eliminate porosity if the spot weld is too large.

6. The principal variable influencing the nugget size, provided the electrode shape and force are established, is the magnitude of the welding current.

7. It may not be necessary to weld Inconel "X" less than 0.062-in. thickness following the schedules used in this report. Other investigators[1-3] have indicated different techniques. Nevertheless, for average production procedure wherein excessive care is not used for control of electrode shape, etc., it is advisable to adhere to the general procedure used.

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2. Nippes, E. F., Savage, W. F., and Moazed, K. L., "Optimum Spot and Seam Welding Conditions for Inconel 'W'," *Ibid.*, 36 (3) Research Suppl., 127-s to 136-s (1956).
3. "Resistance Welding of Nickel and High Nickel Alloys," Technical Bulletin T-33, International Nickel Co., Inc.
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Appendix A

The X-ray equipment used in this work was manufactured by Kelley-Koett Manufacturing Co.

1. 100-A-4 tube unit, self-rectified generator.
2. 100 P.K.V. at 10 ma water cooled.
3. Control type 90-A-4.

Lead shield was used to cover all material except weld spots.

The tube distance above the work was 18 in.

The tube was operated at 10 ma for 20 min on all thicknesses of materials.

The X-ray schedule

Total material thickness, in.	*Operating voltage, volts*	*P.K.V.*
0.064	140	58
0.124	155	65
0.186	180	76
0.250	200	85
0.286	215	92
0.376	240	100

ELEMENTS OF JOINT DESIGN FOR WELDING

A number of important factors which should be considered in the design of welded joints are discussed by the author

BY K. H. KOOPMAN

INTRODUCTION. This paper is an attempt to present a few of the more important factors which should be considered in the design of welded joints. Another aim of the paper is to stimulate more interest in this subject and to encourage design engineers to exploit the wealth of information and data contained in the WELDING HANDBOOK of the AWS[1] and in papers published in THE WELDING JOURNAL and by the Welding Research Council.

This paper discusses the design of joints which are to be fusion welded by any of the arc or gas processes and would apply to either manual or machine welding.

Importance of Good Joint Design

Proper joint design is a vital part of a welding procedure because it helps to control distortion, minimizes residual stresses, facilitates good workmanship and reduces welding costs and results in greater reliability.

The designer should work closely with the welding engineer and metallurgist as well as with the fabricating shop in order to insure the quality of materials and workmanship assumed in his design. In other words, the design engineer at an early stage should assume the responsibility of integrating the fabrication and quality-control techniques into the design in order to assure successful service operation of the finished welded product.

The designer can contribute substantially to the success of his design and at the same time ease the burden placed on the shop in achieving high quality. Too frequently, the designer tends to leave the problem of achieving high-quality welds up to the welding engineer without considering the basic design configurations and fabrication sequence when first starting the design work. If these factors were handled properly in the initial phases of the design, problems likely to be encountered in fabrication and service would be minimized.

Quite often, operations such as stress relieving are overlooked by the designer and later cause trouble. The ASME Code and good safe design require such a stress relief on all welds made of certain materials, e.g., 2¼% chromium–1% molybdenum steel. In other cases, the code suggests stress relief of certain materials for some applications. Such stress-relieving requirements must be factored into the design both from the standpoint of assembly and the use of dissimilar materials. It might be necessary to forego stress relief in certain weldments involving the use of both austenitic and ferritic steels or the use of rolled-in tube-to-tube sheet joints.

The weld joints should be designed so the welds can be tested nondestructively for necessary quality control, especially if the welds are in pressurized or contaminated and inaccessible areas.

The major consideration in joint design is the service for which the product is intended. If the joint is to be subjected to corrosion or erosion, care should be taken to provide welded joints which will present few irregularities or crevices susceptible to such forms of attack or which are difficult to inspect. Full penetration welds are recommended. The manner in which stress will be applied in service, whether tension, shear, bending or torsion, should be considered. Certain joint designs are suitable only for stress applied in one direction, while others are suitable for use when applications of stress are varied or when stress directions are not predictable. Whether the loads are static or dynamic will also affect the weld design.

Typical weld-joint designs are described in Chapter 39 of the WELDING HANDBOOK, Third Edition, and properties of welded joints are described in Chapter 40. In addition, the joint designs shown in MIL-STD-22 (Ships) 30 Aug. 1955 should be referred to when required for military applications.

A great amount of design information for welded buildings and bridges is given in Chapters 47 and 48 of the WELDING HANDBOOK, Third Edition.

Chapter 51 of the WELDING HANDBOOK contains a substantial amount of very helpful information and data on the general use of welding for fabrication of pressure vessels and boilers. Extreme conditions of present-day pressure-vessel operation include boiler pressures up to 2600 psi and temperatures up to 1400° F and as low as minus 350° F. At temperatures in excess of approximately 650° F, low-carbon steels suffer a loss in tensile properties and undergo plastic flow or

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creep, but steels having suitable alloying elements possess greater strength and creep resistance, thus permitting the use of higher working stresses. At temperatures lower than 0° F (below 100° F in some cases) steel should be examined with particular reference to notch toughness and resistance to brittle fracture.

In reference to the welding of machinery components, it should be emphasized that the life of any welded machine depends on proper design. Two general types of welds are used in making strength joints on machinery, butt welds and fillet welds. Tensile and shear stresses for butt welds are usually calculated by dividing the force by the cross-sectional area of the weld. Maximum bending stresses are calculated by dividing the bending moment by the section modulus of the weld. When combinations of tensile, shear or bending stresses are present, they all must be taken into consideration as shown later in this paper.

Stress Concentrations

Local discontinuities and abrupt changes in the section of a member cause a concentration of the stresses at these points and are usually called "stress raisers." The importance of stress raisers and the resulting stress concentrations are dependent upon the ductility of the material and the type of loading, that is, whether it is fast or slow impact, static or dynamic for many cycles.

Stress concentrations in ductile material subjected to static loads are generally not serious because the metal can yield or flow plastically to neutralize or redistribute the stress. However, stress concentrations should be minimized in the case of impact, low temperature or cyclic loading. Since brittle materials will not flow plastically, no redistribution of stress occurs and danger of failure occurring at points of stress concentration will result. Stress concentration in members subjected to fatigue loading might produce failures and should be avoided or properly considered when calculating the size of the member.

A fatigue failure is governed by two factors: the ability of the material itself to withstand repeated stresses and the existence of points at which the stress exceeds the endurance limit of the material. Stress raisers resulting from sharp corners, fillets, notches, holes, etc., might produce stress concentration equal to many times the average stress and, unless these peak values are held below the endurance limit, ultimate failure in service will result.

Two methods may be used to prevent fatigue failures as a result of stress concentration.

1. Eliminate as nearly as possible the stress concentrations.
2. Design the member so that the maximum stresses at the points of stress concentration are below the endurance limit by a suitable factor of safety.

Welded joints, because of their character and shape, are often stress raisers. A small round hole in a plate will produce a theoretical stress-concentration factor as high as 3, and a small gas hole or slag inclusion is not uncommon in welds (other shape holes may be higher in strain raising). Sharp corners and notches are well-known stress raisers and are obtained with groove welds having incomplete penetration, at the heel and toe of fillet welds and at points of undercut or reinforcement. Welded joints subjected to dynamic loads should be designed with these factors in mind. Stress raisers resulting from the weld shape or poor quality should be eliminated as much as possible.

Actually, tensile strength, yield strength, creep trength or long-time rupture strength determines present-day ASME Pressure Vessel Code allowable stresses, ductility and shock and fatigue resistance being taken care of in some degree by material specifications and other test requirements. With further progress, creep and rupture tests will possibly contribute more than comparative evaluation, and the selection of allowable stresses may reflect better evaluation of the flow characteristics, rupture patterns and ductility as determined by these tests. Proper selection of working stresses also involves design and service considerations, which will be considered more broadly under "Design."

These material properties, the influence of abrupt structural discontinuity (plate—heat-affected zone—weld) and the unworked deposited metal must be considered in establishing joint efficiencies. There is a tendency to overvalue the greater tensile strength of many welds with perhaps too little attention to lower ductility in the heat-affected zone, which is the critical area for failure under sudden or repeated loading. On materials which undergo transformation, full heat treatment is beneficial in minimizing this weld-zone discontinuity, subcritical stress relief being of only nominal benefit. Joint efficiencies also depend on design and inspection requirements and are discussed further under "Design."

Design—General

The application of modern welding to pressure vessels and boilers has made possible improved design approaching uniform strength throughout each vessel which, together with advances in mechanics and metallurgy, has pointed the way to more economical use of materials. However, as a pressure membrane of uninterrupted stressed-skin structure is approached, the hazard of propagating minor flaws is increased. Also, over-all economic considerations dictate design for complete rather than average safety, since damages incident to a small fraction of 1% failures would offset material and fabrication savings on the entire production. Accordingly, safety codes and designers must proceed cautiously with reduction in safety factors, considering all contributing factors (service, materials, fabrication, inspection and design) and await each advance to be adequately proved by service experience before sanctioning the next step.

Pressure and temperature, while principal factors, are not the only design criteria. Other loadings must be considered even though the codes are just beginning to adopt specific rules for handling them. Such load-

ings include dynamic shock, fluctuating and repeated pressure loading, thermal stresses (both steady state and transient), superimposed loadings, piping reactions, reactions of platforms and attached equipment and others.

So-called factors of safety are significant only in relation to simplified tensile tests and do not apply beyond single applications of load; at elevated temperature they are questionable. The original ASME Code safety factor of 5 (based on tensile strength) has been reduced to 4 in the API-ASME rules and in the Alternate Rules of the ASME Unfired Pressure Vessel Code, with added design and fabrication restrictions. Increased stresses are also permissible on boiler drums under certain restrictions. With the variety of design and fabrication details permitted, the true safety factor is dependent on the magnitude of localized stress in combination with the resistance of the material to maintained, sudden or repeated loading. With more knowledge of design, properties of materials, control of fabrication techniques and methods of testing the finished product, such extensive use of safety factors as props will not be used. This will require research and development effort on a grand scale.

The present basis of the ASME Boiler Construction Code, Sections I and VIII, allowable stress, Tables P-7 and UCS-23, respectively, is covered by the following statement prepared by the ASME Subgroup on Stress Allowances for Ferrous Materials:

"The tables of allowable stresses are grouped according to temperature and in every case the temperature is understood to be the actual metal temperature.

"The stresses given in P-7, UCS-23 and UHA-23 are based on 25% of the minimum tensile strength according to specifications except for bolting materials and other exceptions given in these references.

"The allowable stresses are based on 80% of the stress required to produce a creep rate of 0.01% per 1000 hr. Since 1944, stress-rupture data when available have been given consideration on the basis that the allowable stress should not exceed 50% of the stress to produce rupture at the end of 100,000 hr. However, during the interval, the creep data have been the limiting consideration. It should be noted that stresses set prior to 1944 have not been readjusted to meet the stress-rupture criterion.

"In the transition range between where 25% of the tensile strength governs and where 80% of the stress to produce a creep rate of 0.01% per 1000 hr governs, allowable working stresses shall not exceed 50% of the yield strength for 0.2% offset."

It is generally recognized that materials and joints must possess a certain ability to absorb energy and to deform plastically under actual stress conditions. Ship and large pressure-vessel failures in recent years have emphasized the hazards of this problem. For low-temperature service below −20° F, the ASME Unfired Pressure Vessel Code, at present, requires that all materials and welds be impact tested. The applicability of the arbitrary temperature of −20° F for all materials is currently under study.

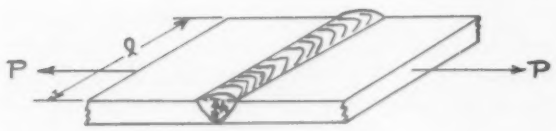

Fig. 1 Butt weld

Formulae based on the theory of elasticity are used for the entire temperature range, although it is realized that plastic flow or creep proportional to stress tends to equalize stress distribution at high temperatures. The margin is in the direction of safety with higher temperatures. The simple stress theory is employed.

Details of welding applications for fabricating welded components for ships, railroads, automotive products and aircraft are given in Chapters 52, 53, 54 and 55, respectively, of the WELDING HANDBOOK, Third Edition. Chapters 56 and 57 cover the design of welded joints for use in transmission pipe lines and industrial piping.

In order to spread the use of standard welding symbols it would be of great assistance if all design engineers and draftsmen would use the symbols presented in Chapter 58 of the WELDING HANDBOOK.

Weld-Joint Design

Some simple basic formulae and their derivation and use in both static and dynamic loading are presented in the following pages. These were first published in Reference 2 by C. H. Jennings.

Symbols

S = normal stress, psi.
S_S = unit shear, psi.
M = bending moment, in.-lb.
I = moment of inertia, in.^{4}
K = stress-concentration factors.
P = external load, lb.
h = size of weld, in.
For fillet weld, h = weld leg.
For butt welds, h = throat, excluding reinforcement.
l = length of weld, in.
L = linear distance, in.

Stresses in Butt Welds

In Fig. 1

$$S = \frac{P}{hl} \tag{1}$$

and max shear stress S_S

$$S_S = \frac{P}{2hl} \tag{2}$$

Let h = thickness of plates of equal thickness.

As an addition to the safety factor for static loading, do not include the weld reinforcement.

Stresses in Fillet Welds

Symmetrical Fillet Welds

Photoelastic tests indicate that the stress at the throat section of transverse fillet welds is principally a tensile stress.

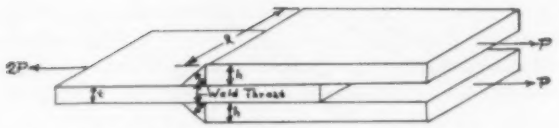

Fig. 2 Symmetrical fillet welds

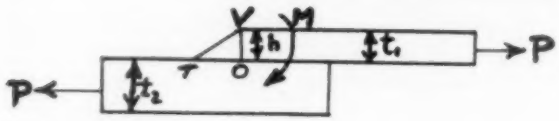

Fig. 3 Fillet weld

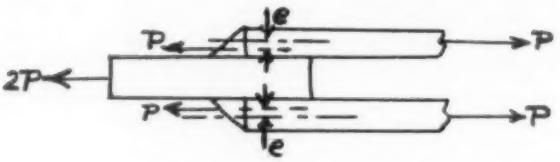

Fig. 4a Eccentricity of load in fillet welds

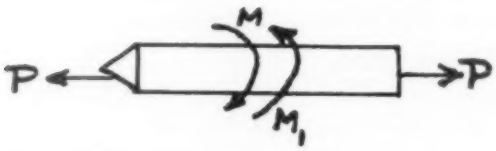

Fig. 4b Bending moment in fillet weld

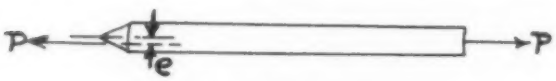

Fig. 4c Eccentric loading in fillet weld

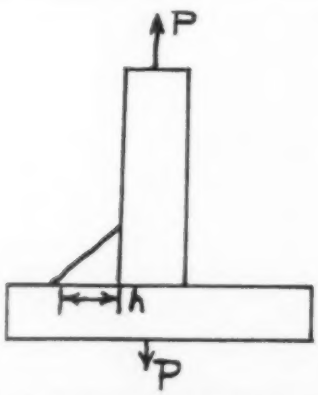

Fig. 5 Nonsymmetrical fillet weld

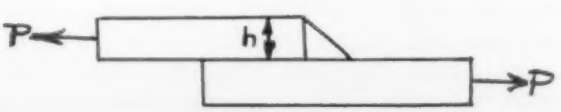

Fig. 6 Nonsymmetrical fillet weld

Throat = $L \cos 45 \text{ deg} = 0.707h$ (see Fig. 2).
In symmetrical fillet welds,

$$S = \frac{P}{\text{weld-throat area}} = \frac{P}{0.707hl} = \frac{1.414P}{hl} \quad (3)$$

The thickness of welded members may limit design. In Fig. 2, the center plate must be $>2h$, and in Fig. 3, the strength of connection may be limited by thickness of thinnest member.

In Fig. 3, where $t_1 \leqq t_2$, the bending moment M is also produced on the weld, so eq 3 above will not suffice. See eq 5.

As in Figs. 4*a* and 4*b* (same as joint in Fig. 2), a transverse force acts between the overlapping surfaces and produces the same bending moment, M_1 as shown in Fig. 4*b*, which acts opposite to the M caused by P.

The force P and moment M_1 can be represented by the force P alone, eccentrically applied as in Fig. 4*c*.

At equilibrium, M_1 is of such a value that the eccentricity, e, causes the load P to act along the centerline of the weld throat.

Therefore, P should be about the same as P in a tensile test of the weld.

Nonsymmetrical Fillet Welds

There is no counteracting M as in the previous case of Fig. 4*a* because the welded plates cannot press against each other. Therefore, we must consider the M resulting from weld-joint eccentricity in these cases shown in Figs. 5 and 6.

In Fig. 7*a*, the weld throat is subjected to a tensile force P and bending moment M resulting from the eccentricity of force P acting along the fusion line OH. $M = P/H$.

The stress caused by direct loading P is:

$$S = \frac{1.414P}{hl} \quad \text{(3) and (4)}$$

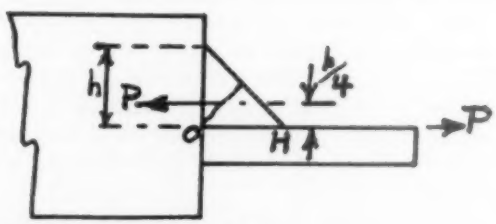

Fig. 7a Eccentric loading

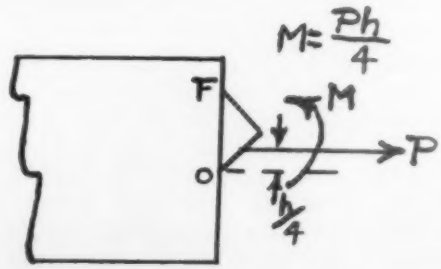

Fig. 7b Bending moment

The stress resulting from M is:

$$S = \frac{6M}{(0.707h)^2 l} = \frac{6Ph}{4(0.5)h^2 l} = \frac{3P}{hl} \qquad (5)$$

This bending stress increases the stress at the weld root, O, and decreases the stress at F. The root stress is critical.

Add eqs (4) and (5) for the stress in nonsymmetrical fillet welds:

$$S = \frac{1.414P}{hl} + \frac{3P}{hl} = \frac{4.414P}{hl} \qquad (6)$$

For a given load P, the stress is

$$\frac{4.414P/hl}{1.414P/hl} = \frac{4.414}{1.414} =$$

3.1 times the stress obtained by eq (3)

for a symmetrical fillet weld of the same size.

Parallel Fillet Welds

For design practice, assume that parallel welds are subjected to shearing stresses only.

For the single fillet weld shown in Fig. 8,

$$S_S = \frac{P}{0.707hl} = \frac{1.414P}{hl} \qquad (7)$$

For a double fillet weld,

$$S_S = \frac{P}{2. \times 0.707hl} = \frac{0.707P}{hl} \qquad (8)$$

For welds made in plates of unequal thickness, the plate sections between the welds do not distribute the load uniformly. As an analogy, imagine rubber for the top plate between A and B; then weld A in Fig. 9 carries the complete load. This is considered to be the general case for ductile materials, but a careful stress analysis would show peak stress values in the top and bottom plates in the weld regions. These stress peaks would be dangerously high for high-strength materials of low ductility.

$$S_A = \frac{a}{(b + a)} \times \frac{1.414P}{h_1 l} \qquad (9)$$

$$S_B = \frac{b}{(b + a)} \times \frac{1.414P}{hl} \qquad (10)$$

If the top plate were thin, failure would occur in the plate near the edge of weld A. If side (parallel) welds are used, eq 8 will apply because the load distribution between the overlapping plates does not greatly affect the load distribution on the welds.

For simplicity, when parallel and transverse fillet welds are used together (see Figs. 10*a* and 10*b*), assume that the load is uniformly distributed between the welds. Actually the transverse welds are subjected to greater stress and will fail first. This is particularly true for materials of low ductility.

For two transverse welds, $S = 0.707P/hl$. For one transverse weld, $S = 1.414P/hl$.

However, the experimental evidence is not sufficient to give an exact analysis. So assume uniform loading in design.

Welds Between an Angle and a Plate

Figure 11 shows a weldment wherein the welds are located between an angle and a plate.

Sometimes, make the center of gravity (c.g.) of the welds coincide with the c.g. of the angle. Let $x - x$ be the c.g. of the angle; b is width of the angle; e_1 and e_2 are the distances from the c.g. to the sides of the angle.

To have the c.g.s coincide, $l_1 e_1$ must equal $l_2 e_2$ if the fillet welds are the same shape and leg size.

If stress were the same in both welds,

$$S = \frac{1.414P}{h(l_1 + l_2)} \qquad (11)$$

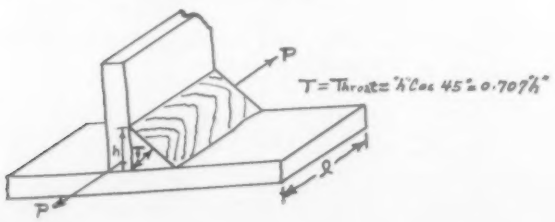

Fig. 8 Loading parallel to fillet weld

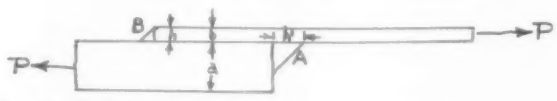

Fig. 9 Eccentric loading

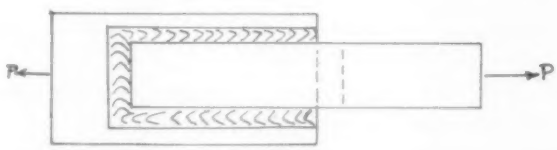

Fig. 10a Fillet welds

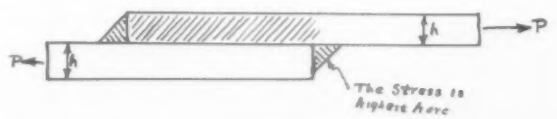

Fig. 10b Point of highest stress in fillet welds

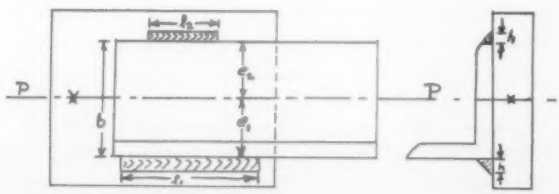

Fig. 11 Angle welded to plate

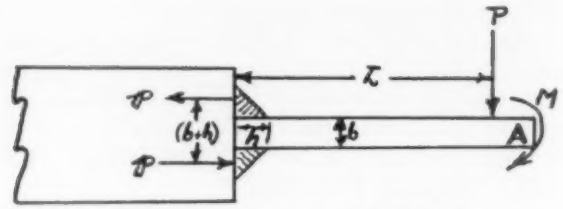

Fig. 12 Transverse fillet welds under bending

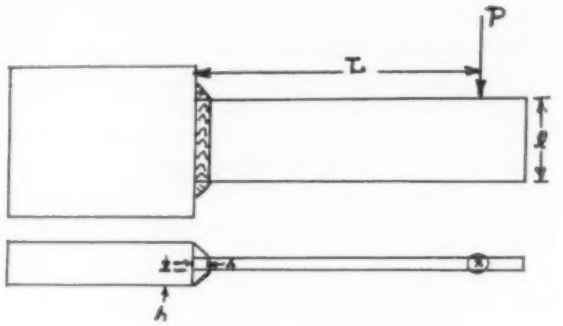

Fig. 13 Parallel fillet welds under bending

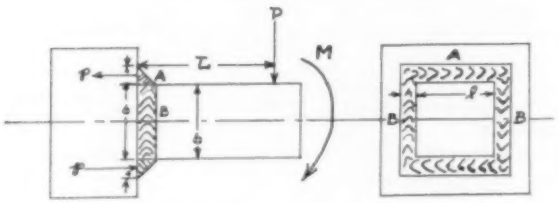

Fig. 14 Fillet-welded bar

Since

$$l_2 = l_1 e_1 / e_2 \tag{12}$$

$$S = \frac{1.414P}{h[l_1 + (l_1 e_1)/e_2]} = \frac{1.414Pe_2}{hl_1(e_2 + e_1)} = \frac{1.414Pe_2}{hl_1 b} \tag{13}$$

Similarly,

$$S = \frac{1.414Pe_1}{hl_2 b} \tag{14}$$

However, it is not necessary to design so that c.g.s of the angle and of the welds coincide.

Transverse Fillet Welds Loaded in Bending

Assume the bending moment M is counteracted by a couple composed of forces p acting at the center of the weld legs, as shown in Fig. 12. Therefore, $M = p(b + {}^1/_2h + {}^1/_2h) = p(b + h)$ or

$$p = \frac{M}{(b + h)} \tag{15}$$

The weld stress from the bending moment alone equals

$$S = \frac{1.414p}{hl} = \frac{1.414M}{hl(b + h)} \tag{16}$$

The load P exerts a shear stress as well as the bending moment pL. These must be combined. The following equations agree with actual test data.

Assume both welds are of same length l. The shearing force on each weld $= P/2$. From eq 15, the force of bending moment on each weld is

$$p = \frac{M}{(b + h)} = \frac{PL}{(b + h)}$$

Determine the weld stress by calculating the resultant of these two forces and dividing by the area of the weld throat.

Bending moment force, $p = PL/(b + h)$

$$S = \frac{\sqrt{\left(\frac{P}{2}\right)^2 + \left(\frac{PL}{b + h}\right)^2}}{\cos 45 \text{ deg} \times hl} = \frac{1.414\sqrt{\left(\frac{P}{2}\right)^2 + \left(\frac{PL}{b + h}\right)^2}}{hl} \tag{17}$$

since $1.414 = \sqrt{2}$

$$S = \sqrt{2\left[\frac{P^2(b + h)^2 + 4P^2L^2}{4(b + h)^2}\right]} = \frac{P}{hl(b + h)}\sqrt{2L^2 + \frac{(b + h)^2}{2}} \tag{18}$$

If $(b + h)$ is small in comparison to L, eq 18 approaches eq 16 for pure bending.

Parallel Fillet Welds Loaded in Bending

Calculate stresses on the basis of weld-throat sections being subjected to bending moment. On each weld,

$$M = PL/2 \text{ (see Fig. 13)} \tag{19}$$

The section modulus of the throat $=$

$$\frac{0.707hl^2}{6} \tag{20}$$

$$S = \frac{M}{\text{Section Modulus}} = \frac{PL/2}{0.707hl^2/6} = \frac{6PL}{1.414hl^2}$$

$$S = \frac{4.24PL}{hl^2} \tag{21}$$

Bar Fillet Welded on All Sides and Subjected to Bending

Referring to Fig. 14, M_1 is resisted by transverse welds A, and can be calculated by eq 16.

$$S_1 = \frac{1.414M_1}{hl(b + h)}; M_1 = \frac{S_1 hl(b + h)}{1.414} \tag{22}$$

M_2 is resisted by parallel longitudinal welds B and can be calculated from eq 21.

$$S_2 = \frac{4.24M_2}{hb^2}; M_2 = \frac{S_2 hb^2}{4.24} \tag{23}$$

If the maximum stress were the same in all the welds, then $S_1 = S_2$. Therefore,

$$\frac{1.414M_1}{hl(b + h)} = \frac{4.24M_2}{hb^2}$$

$$M_1 = M_2 \frac{3l(b + h)}{b^2} \tag{24}$$

but $M = M_1 + M_2 = M_2 \dfrac{3l(b + h)}{b^2} + M_2$

$$M = M_2\left[1 + \frac{3l(b + h)}{b^2}\right] \qquad (25)$$

Substitute value of M_2 from eq 25 in eq 23, $M_2 = M/\left[1 + \dfrac{3l(b + h)}{b^2}\right]$

$$S = S_1 = S_2 = \frac{4.24M_2}{hb^2} = \frac{4.24}{hb^2} \cdot \frac{M}{\left[1 + \dfrac{3l(b + h)}{b^2}\right]}$$

$$S = \frac{4.24M}{hb^2\left[\dfrac{b^2 + 3l(b + h)}{b^2}\right]} = \frac{4.24M}{h[b^2 + 3l\ (b + h)]} \qquad (26)$$

Fillet-Welded Shaft Subjected to Bending

The stress in each element of weld shown in Fig. 15 is proportional to its distance from the neutral axis.

The stress in the weld throat is 1/cos 45 deg or 1/0.707 times the shear along the fusion edge of weld.

An elementary area of fusion zone, $dA = hrd\alpha$ at an angle α with the neutral axis, is subjected to a shearing force df.

Stress will be

$$dS = \frac{\text{force}}{\text{area}} = \frac{df}{hrd\alpha} \qquad (27)$$

If S_S is maximum shearing stress $S_S/r = dS/r \sin \alpha$, since stress is proportional to the distance from neutral axis.

$$S_S = \frac{dS}{\sin \alpha}; dS = S_S \sin \alpha \qquad (28)$$

From eq 27, $df = ds\ hr\ d\alpha$

$$df = S_S \sin \alpha hrd\alpha \qquad (29)$$

The bending moment developed by df is $dm = df\ (r \sin \alpha)$

$$dm = S_S \sin \alpha hrd\alpha r \sin \alpha = S_S \sin^2 \alpha hr^2 d\alpha \qquad (30)$$

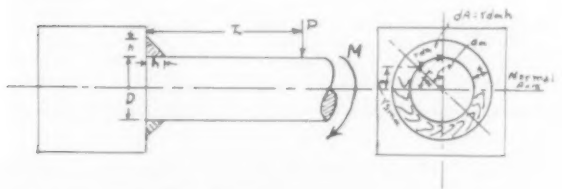

Fig. 15 Fillet-welded shaft

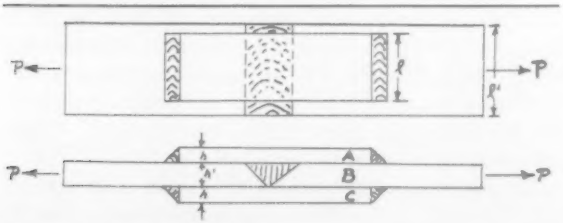

Fig. 16 Welded butt straps

$$M = \int_0^{2\pi} S_s \sin^2 \alpha hr^2 d\alpha = S_s hr^2 \int_0^{2\pi} \sin^2 \alpha d\alpha$$

Since

$$\int_0^{2\pi} \sin^2 \alpha d\alpha = -{}^1/_2 \cos \alpha \sin \alpha + {}^1/_2\alpha \Big]_0^{2\pi}$$

or

$$= {}^1/_2\alpha - {}^1/_4 \sin 2\alpha \Big]_0^{2\pi}$$

$$= [\pi - 0] - [0 - 0] = \pi$$

$$M = S_s hr^2\pi;\ S_s = \frac{M}{hr^2\pi} \qquad (31)$$

for the shearing stress developed in the fusion zone of weld.

For the throat of the weld,

$$S_s = \frac{M}{0.707hr^2\pi}$$

$$r = \frac{D}{2}, S = \frac{M}{0.707(D^2/4)\pi}$$

$$S = \frac{4M}{0.707hD^2\pi} = \frac{5.66M}{\pi hD^2} \qquad (32)$$

Fillet-Welded Shaft Subjected to Torsion

Torque M is resisted by shearing force in weld throat acting at a distance $D/2$ from center of shaft

$$M = \text{shearing force} \times \text{distance},\ D/2 \qquad (33)$$

$$M = S_s \times \text{throat area} \times D/2$$

$$S_s = \frac{2M}{\text{throat area} \times D} = \frac{2M}{0.707h\pi D \times D} = \frac{2M}{0.707\pi D^2 h}$$

$$S_s = \frac{2.83M}{\pi hD^2} \qquad (34)$$

Fillet-Welded Butt Straps

Butt-weld joints in tension are sometimes strengthened for static loading by adding a butt strap to carry part of the load because the design stress of the weld metal is not as high as that of the base metal. However, it should not be used for dynamic loading; in such cases, butt welds are preferable because stress concentrations are reduced.

The addition of a butt strap on both sides is preferred, as shown in Fig. 16. (If only one strap can be added, place it on the root side of the weld.)

The elongation is the same in all plates when joint is loaded.

Since Y = stress/strain, Stress = $Y \times$ strain = $Y \times$ elongation/in. and since Y and the strain are the same for plates A, B and C inside of welds, the stress is, therefore, the same for all plates made of the same material.

Since the loads transmitted by the plates equal the stress times cross-sectional area and since the stresses are equal, the loads are proportional to the cross-sectional area.

Table 1—Allowable Working Stresses for Butt Welds in Carbon Steel

	—For static loading—		—For dynamic loading—		
	*Psi**	*Safety factor**	*Psi**	*Safety factor**	
Tension	17,000	3.5	8000	3.25	Based on endurance limit
Compression	20,000	3.0	8000	3.25	
Shear	10,200	60% of tension working stress	4800	60%	of tension value

* These are nominal values. Refer to the WELDING HANDBOOK and to the codes for suggested current values.

Load in each butt strap (Fig. 17) = p =

$$P \times \frac{\text{cross section of one butt strap}}{\text{total cross-sectional area}} = p = P\frac{hl}{(2hl + h_1l_1)} \quad (35)$$

Load in the butt-welded plate = p_1

$$= P\left(\frac{\text{cross section of butt-welded plate}}{\text{total cross-sectional area}}\right) = P\frac{h_1l_1}{(2hl + h_1l_1)} \quad (36)$$

S_{Fillet} = Stress in fillet welds =

$$\frac{p}{\text{weld-throat area}} = \frac{p}{0.707hl} = \frac{Phl}{(2hl + h_1l_1)0.707hl} = \frac{1.414P}{(2hl + h_1l_1)} \quad (37)$$

S_{Butt} = Stress in butt weld =

$$\frac{p_1}{\text{cross-sectional area normal to load}} = \frac{Ph_1l_1}{(2hl + h_1l_1)h_1l_1} = \frac{P}{(2hl + h_1l_1)} \quad (38)$$

Design for Fatigue-Type Loads

When structures of any type are subjected to repeated fatigue-type loads of any type, they should be designed for lower working stresses. Some typical values shown in some of the welding literature are listed in Table 1.

Table 2 presents a summary of the allowable stresses.[10] In particular, the conditions to be considered are summarized in connection with the allowable stress symbols.

For fillet welds, use lower working stresses. For static tension, compression or shear, use 14,000 psi.

For $^1/_8$-in. fillet, for example, $^1/_8$ in. × 14,000 = 1750 lb/in. of weld. For $^1/_2$-in. fillet, $^1/_2$ in. × 14,000 = 7000 lb/in. of weld.

For endurance limit of fillet welds, that is, for dynamic tension, compression and shear working stresses, use 5000 psi for either transverse or parallel welds in C steel.

Low working stresses are necessary because of stress-concentration factors, K. Some typical values are listed in Table 3.[2]

Table 2—Summary of Design Stress Limits

Stress	*Limit symbol*	*Limitation on maximum shear stress*	*Load condition considered*	*Discontinuities considered* Gross	Local
S_{wo}*	τ_M†	Membrane 60% yield strength (shear) or 20% U. S. whichever is less	Internal pressure steady-state forces	Yes	No
..	$\tau_p = 1.5\tau_M$	Peak 90% yield strength (shear) or 30% U. S. whichever is less	Internal pressure pipe reactions, steady-state forces	Yes	No
Y. S.	$\tau_{MS} = 1.67\tau_M$ 25,000	Peak—mean component 100% yield strength (shear) or 33.3% U. S. whichever is less	Internal pressure pipe reactions, steady-state forces steady-state thermal	Yes	No
S_{sc}	τ_{AM} 15,000	Peak-alternating components; 100% endurance limit (shear)	Transient mechanical	Yes	No
KS_e	τ_{AS} 25,000	Peak-alternating component. Endurance strength (shear) at 10^8 cycles or yield strength in shear, whichever is less	Transient mechanical; transient thermal	Yes	No

* See Reference 2—these symbols used in eqs 39 and 40.
† See References 9 and 10.

Table 3

Location	*K value*
At edge of reinforced butt weld	1.2
At toe of transverse fillet weld	1.5
At end of parallel fillet weld	2.7
T-butt joint with sharp corners	2.0

Cazaud[11] showed that the fatigue strength of welds in a low-alloy Cr-Cu steel of 76,000 psi ultimate tensile strength varied with the joint geometry. Joints having more severe notches or stress-concentration factor K had a lower fatigue strength when tested in fluctuating direct stress fatigue. The stress-concentration factors varied from 1.3 for a transverse weld bead-on-plate to 3.0 for transverse fillet-welded cover plates. These values are quite close to those listed in Table 3.

Fatigue tests of arc-welded mild steel of 37,000 psi yield strength and 57,000 psi ultimate tensile strength indicated the K values listed in Table 4.

Table 4—Direct Stress Fatigue Tests (2 X 10^6 cycles)

Form of test piece	Mean stress 25,500 psi; limiting range of stress, Psi	%	K Values
Unwelded bar	11,400	100	1.0
Single-V butt weld	6,400	56	1.8
Double-V butt weld	5,700	50	2.0
Single-V butt weld with reinforcement removed	6,400	56	1.8
Single-V butt weld with transverse fillet-welded butt straps	4,200	37	2.7
Similar model machined from solid metal	5,700	50	2.0
Transverse fillet weld—symmetrical	2,100	19	5.2
Longitudinal fillet welds	1,800	15	6.6

The values in Table 4 show that fillet welds introduce a severe stress-concentration effect and that it would be advisable to design for smooth butt welds wherever possible. Combined static and dynamic loads are encountered in many structures.

A direct variable stress can be resolved into two parts, a constant mean or steady stress and a variable or reversed stress. In Fig. 18, the yield strength and ultimate tensile strength in a static tension test ($KS_v = 0$) are shown along with the endurance limit for reversed stress ($S_0 = 0$). Assume that the limiting stress conditions for other cases are represented by points on these straight lines. If the endurance limit and yield strength or tensile strength are divided by the factor of safety, a straight line parallel to one of these lines results and represents safe design stress limits. Safe values of variable stress, KS_v and steady stress, S_0 can then be determined by this line. The endurance limit will be a function of the number of cycles of stress to be withstood in service.

Fatigue might be considered more of a problem in machine components than in pressure vessels. However, pressure-vessel stresses in service are increased and made more complex by thermal cycling and transient loads from vibration or impact, and should be scrutinized more carefully in an effort to improve the quality of design work.

The equation of the straight line relating steady stress, S_0 and the variable stress, KS_v (Fig. 18) and joining the variable working stress, S_{wv} and the steady working stress, S_{wo} is:

$$\frac{KS_v}{S_{wv}} + \frac{S_0}{S_{wo}} = 1 \qquad (39)$$

Steady stress, $S_0 = {}^1/_2(S \text{ max} + S \text{ min})$. Variable stress (in dynamic loading), $KS_v = K \times {}^1/_2(S \text{ max} - S \text{ min})$

$$\frac{K(S \text{ max} - S \text{ min})}{2S_{wv}} + \frac{(S \text{ max} + S \text{ min})}{2S_{wo}} = 1$$

$$KS \text{ max } S_{wo} - KS \text{ min } S_{wo} + S \text{ max } S_{wv} + S \text{ min } S_{wv} = 2S_{wv}S_{wo}$$

$$S \text{ max } (S_{wv} + KS_{wo}) + S \text{ min } (S_{wv} - KS_{wo}) = 2S_{wv}S_{wo} \qquad (40)$$

Simplified Examples

Consider a butt weld in 1-in. thick steel plate with the weld reinforcement retained.

The tensile load varies from 10,000 to 40,000 psi. Obtain S max and S min in terms of the load, and calculate the weld size.

From eq 1, $S = P/hl$ for butt welds.

$$S \text{ min} = \frac{10{,}000}{1 \text{ in.} \times l} = \frac{10{,}000}{l}$$

$$S \text{ max} = \frac{40{,}000}{1 \text{ in} \times l} = \frac{40{,}000}{l}$$

Variable (dynamic) working stress, $S_{wv} = 8000$ psi. Steady (static) working stress, $S_{wo} = 17{,}000$ psi.

Use other values for compression or shear.

Substitute in eq 40. Use $K = 1.2$.

$$\frac{40{,}000}{l}(8000 + 1.2 \times 17{,}000) + \frac{10{,}000}{l}(8000 - 1.2 \times 17{,}000) = 2 \times 8000 \times 17{,}000\frac{0.40}{l}(8000 + 20{,}400) + \frac{0.10}{l}(8000 - 20{,}400) = 0.16 \times 17{,}000 =$$

$$2720\frac{0.4 \times 28{,}400}{l} + \frac{0.1(-12{,}400)}{l} = 2720\frac{11{,}360}{l} - \frac{1240}{l} = 2720; \quad 11{,}360 - 1240 = 2720 \times l$$

$$l = \frac{10{,}120}{2720} = 3.72 \text{ in. for dynamic loading}$$

For static loading in tension, $S = P/hl$, $l = P/hS$.

$$l = \frac{4000 \text{ max}}{1 \text{ in.} \times 17{,}000} = 2.35 \text{ in., which is too short}$$

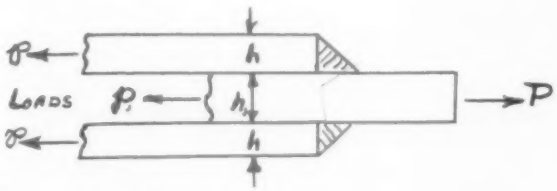

Fig. 17 Loading on welded butt straps

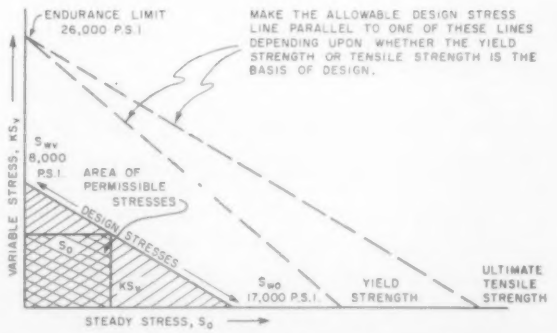
ENDURANCE LIMIT 26,000 P.S.I.
MAKE THE ALLOWABLE DESIGN STRESS LINE PARALLEL TO ONE OF THESE LINES DEPENDING UPON WHETHER THE YIELD STRENGTH OR TENSILE STRENGTH IS THE BASIS OF DESIGN.
VARIABLE STRESS, KSv
Swv 8,000 P.S.I.
AREA OF PERMISSIBLE STRESSES
DESIGN STRESSES
So
KSv
Swo 17,000 P.S.I.
YIELD STRENGTH
ULTIMATE TENSILE STRENGTH
STEADY STRESS, So

Fig. 18 Variable and steady stress relationship

and would be a dangerous design for fatigue type or dynamic loading. It would fail in fatigue.

If the load varied from 40,000 psi tension to 40,000 psi compression,

$$S \text{ min} = \frac{-40{,}000}{l}$$

$$S \text{ max} = \frac{40{,}000}{l}$$

$$\frac{40{,}000}{l}(28{,}400) - \frac{40{,}000}{l}(-12{,}400) = 272 \times 10^6$$

$$\frac{11{,}360}{l} + \frac{4960}{l} = 2720;\ 2720 \times l = 16{,}320$$

$$l = \frac{16{,}320}{2720} = 6 \text{ in.}$$

Again, the value of $l = 2.35$ in. based on simple tension would be a dangerous design and the weld would fail in fatigue, probably with relatively few cycles.

If the welded joint is subjected to compression, use a value of working stress, $S_{wo} = 20{,}000$ psi and $S_{ws} = 8000$ psi. For shear, $S_{wo} = 10{,}000$ psi and $S_{ws} = 5000$ psi are good representative values.

For higher strength alloy steels, possibly use higher values of S_{wo} and S_{ws}.* For lower strength Al, Cu and Mg alloys, use lower values of S_{wo} and S_{ws}.

The alloy vendors and producers should be contacted for design data. An example of a typical calculation:

Obtain S in terms of load, P, length of weld, l, diameter, D, size of fillet weld h (or thickness of plate, h).

Consider a fillet-welded round shaft subjected to bending.

Equation 32 $S = \frac{5.66M}{\pi h D^2}$ and $M = PL$. Therefore,

$$S = \frac{5.66PL}{\pi h b^2}$$

Assume an alloy-steel shaft 24 in. long is to be used to support a load which varies from 1000 to 10,000 lb at 20 in. from the welded end.

Obtain S max and S min in terms of load and calculate the weld size using a $^1/_2$-in. fillet weld.

$$S \text{ max} = \frac{5.66\ (10{,}000)\ (20 \text{ in.})}{\pi(^1/_2 \text{ in.})D^2} = \frac{720{,}000}{D^2}$$

$$S \text{ min} = \frac{5.66\ (1000)\ (20 \text{ in.})}{\pi(^1/_2 \text{ in.})(D^2)} = \frac{72{,}000}{D^2}$$

$S_{ws} = 7000$ psi and $S_{wo} = 19{,}600$ psi for alloy steel.

$K = 1.5$ at toe of fillet welds.

Substitute in eq 40:

$$\frac{720{,}000}{D^2}(7000 + 1.5 \times 19{,}600) + \frac{72{,}000}{D^2} \times$$

$$(7000 - 1.5 \times 19{,}600) = 2(7000)\ (19{,}600)$$

$$\frac{720{,}000}{D^2}(36{,}400) + \frac{72{,}000}{D^2}(-22{,}400) = 274 \times 10^6$$

$$\frac{72}{D^2}(3.64) + \frac{7.2}{D^2}(-2.24) = 2.74$$

$$\frac{262}{D^2} - \frac{16.1}{D^2} = 2.74;\ \frac{262 - 16.1}{2.74} = D^2$$

$$D^2 = \frac{245.9}{2.74} = 89.7;\ D = 9.4 \text{ in. diam}$$

From the equation above, $D^2 = 720{,}000/S$ max.

Since the working stress for fillet-welded alloy steel in static loading equals 19,600 psi

$$D^2 = \frac{720{,}000}{19{,}600} = 36.7;\ D = 6.02 \text{ in. diam}$$

which would be a dangerous design when based on static stress and would fail at a relatively low number of cycles in fatigue during service.

If the bar diameter were given, the size of the fillet weld could instead be calculated for this problem.

Conclusion

The previous examples show that welds to be used for cyclic loading or fatigue type service should be designed on the basis of lower allowable working stresses than welds to be used for static loading. The main reason for this caution is the larger part that notches and other stress-concentration factors play in producing fatigue type failures.

In conclusion, it is strongly recommended that design engineers refer to the WELDING HANDBOOK as a first step in designing welded joints. The WELDING HANDBOOK presents a wealth of valuable information as well as directing the designer to the correct codes to be used for all types of welded structures ranging from machinery to pressure vessels and from bridges to aircraft.

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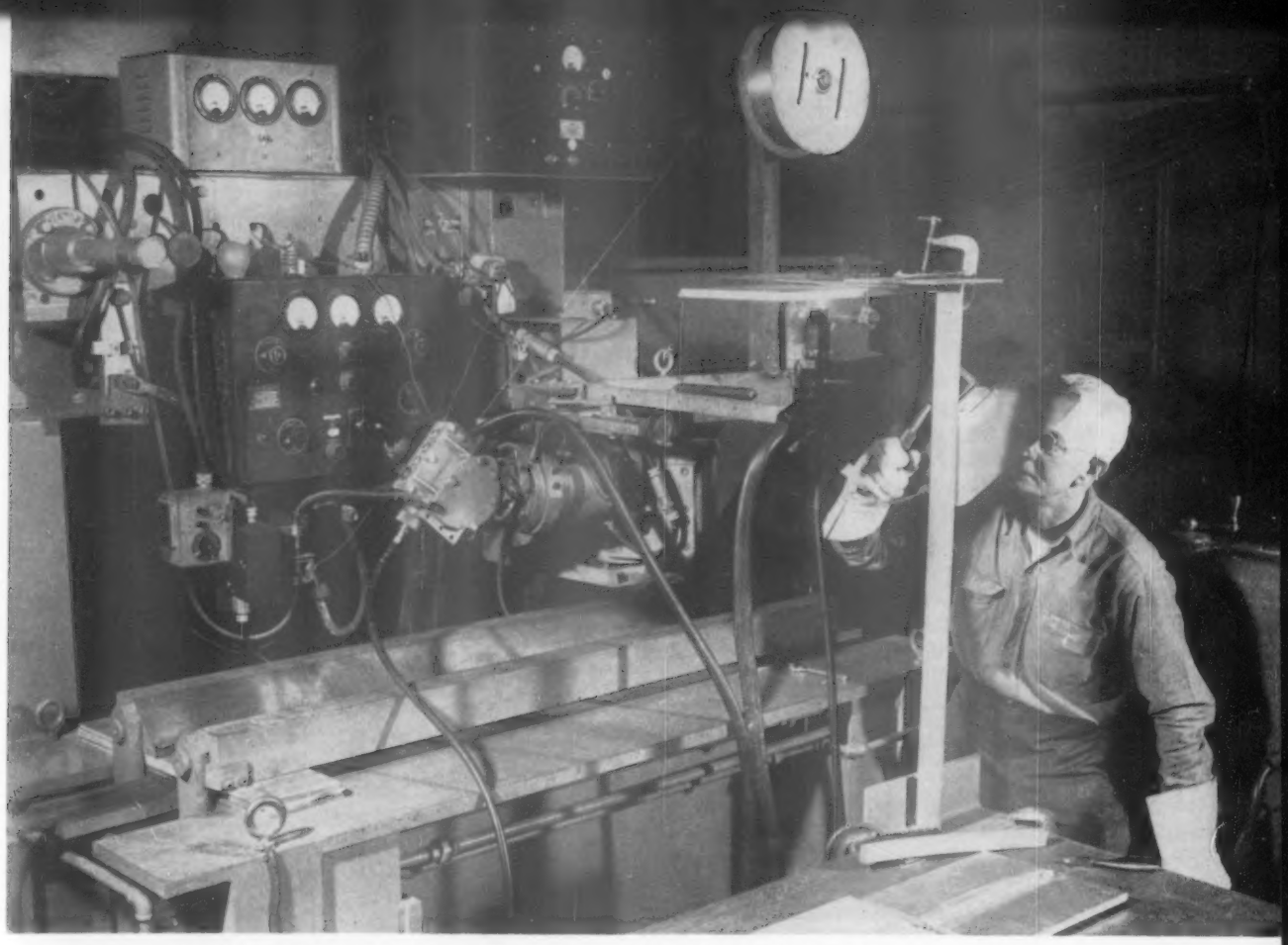
* This is now being investigated by the Welding Research Council.



Automatic overhead consumable-electrode welding equipment for weld-porosity investigations

POROSITY IN ALUMINUM-ALLOY WELDS

Porosity in aluminum-alloy welds is caused by atmospheric contamination of shielding gas rather than by gas in the metal. Helium-argon gas is recommended for consumable-electrode welding

BY F. R. COLLINS

SYNOPSIS. The greatest source of porosity in aluminum-alloy welds is atmospheric contamination of the shielding gas. Hydrogen, formed by the reaction of water vapor with molten aluminum, is responsible for nearly all porosity in aluminum alloys. The use of a helium-argon-mixture shielding gas is recommended to reduce porosity.

Excessive hydrogen in aluminum-alloy plate and electrode can contribute to porosity; but, in general, commercial aluminum products do not contain sufficient hydrogen to make a substantial contribution to porosity.

Aluminum-magnesium alloys give less porosity than aluminum-magnesium-silicon alloys.

Oxygen and chlorine additions to argon reduce porosity but have disadvantages that make them undesirable for most applications.

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Introduction

The inert-gas-shielded consumable-electrode welding process has greatly increased the use of aluminum alloys in welded structures. Unfortunately, welds made by this process can be porous. Porosity has been attributed to hydrogen in the aluminum-alloy plate and wire, certain types of oxide films on the metal, impurities in the shielding gas and welding conditions.

In view of these conflicting beliefs, an investigation was undertaken to determine the causes of porosity in

aluminum-alloy welds. The investigation was confined to the aluminum-magnesium and aluminum-magnesium-silicon alloys most used in welded structures.

The Effect of Gas in Metal on Weld Porosity

Preparation of Plate

Aluminum plate of alloys 6061, 5052 and 5056 was prepared in both the degassed and artificially gassed conditions for comparison with commercial plate. In the laboratory preparation of degassed alloys, the metal was fluxed with chlorine until a sample, slowly frozen under vacuum,[1] showed no escape of gas during this freezing period and no porosity in the frozen sample. For the artificially-gassed alloys, steam was bubbled through the molten metal until the vacuum sample showed a large amount of gas that escaped during the freezing period. These frozen samples contained a large amount of porosity. The vacuum-cast samples of gassed and degassed metal are shown in Fig. 1.

The alloys were cast as direct-chill ingots, then preheated, scalped and rolled into plate. Some alloys were also cast as small tilt-mold ingots which, after preheating and scalping, were extruded into wire.

Heating Tests

The partially melted zone in aluminum plate near the weld bead often contains more porosity than the bead itself. Presumably, the gas bubbles that form in the completely liquid zone can escape, whereas those that form in the mushy zone at the edge of the weld cannot. It has been proposed that the amount of porosity formed in aluminum heated to the mushy state measures the effect of gas in metal on the porosity of welds. In view of this widespread belief, a series of tests of this type was conducted. The effect of heating was determined by density measurements and microscopic examination.

Normal commercial plate, laboratory-fabricated gassed and degassed plate of aluminum-magnesium and aluminum-magnesium-silicon alloys were heated in and just below the solidus-liquidus range in argon. No significant change in density or porosity was noted. This was true even though some specimens were heated until they were rather fluid. Specimens that were heated in air, however, exhibited decreased density and increased porosity. Both effects became more pronounced with increasing temperature. The amount of porosity was essentially the same for gassed, degassed and commercially prepared plate. It was concluded, therefore, that the porosity was caused not by dissolved gas in the plate, but rather by reaction with water vapor in the air during heating.[2] This test was discarded as a suitable method of determining the influence of gas in metal upon weld porosity.

Arc-Welding Tests

In the inert-gas-shielded arc welding of aluminum, it is generally possible to obtain sound downhand welds but much more difficult to obtain sound overhead welds. In downhand welding, the gas bubbles that form can rise to the surface and escape. In overhead welding, however, the bubbles are trapped by the unmelted portion of the plate above the weld pool. Since overhead welds often give porosity where downhand welds do not, overhead welding tests were selected to evaluate the effect of gas in metal on weld porosity.

The aluminum plate was etched in sodium hydroxide,

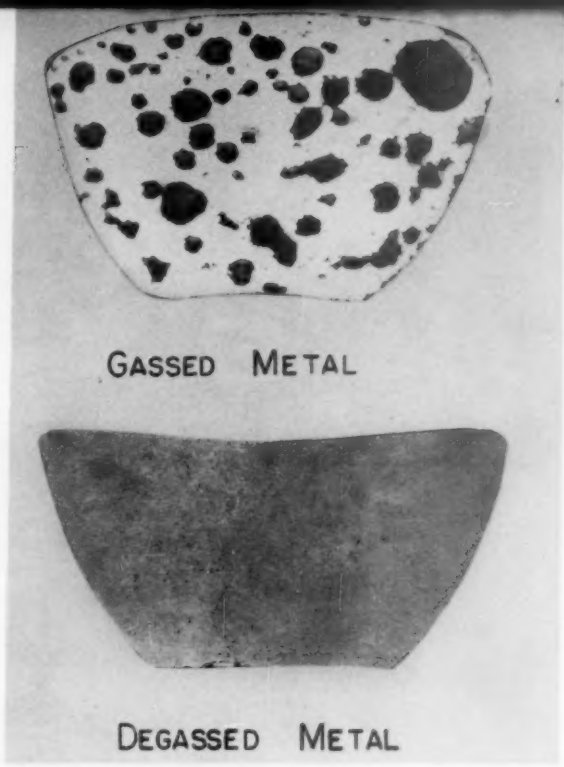

Fig. 1 Porosity in vacuum samples

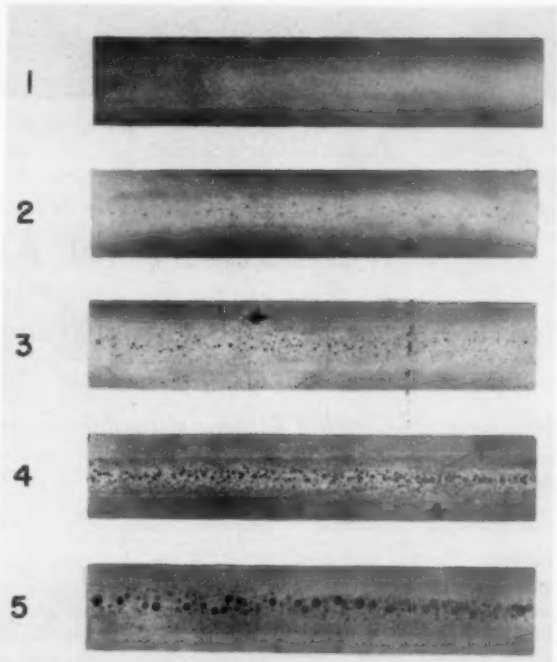

Fig. 2 Weld-porosity ratings

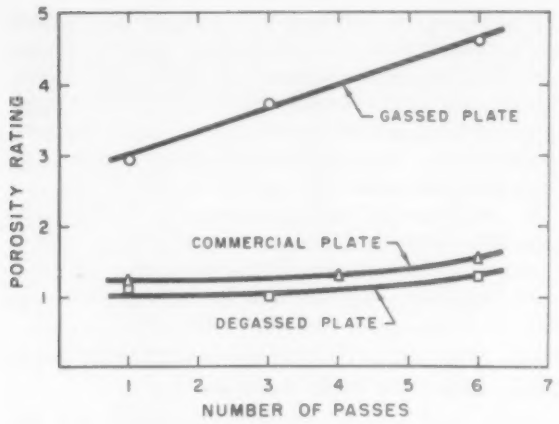

Fig. 3 Porosity in overhead welds in Al-Mg alloys

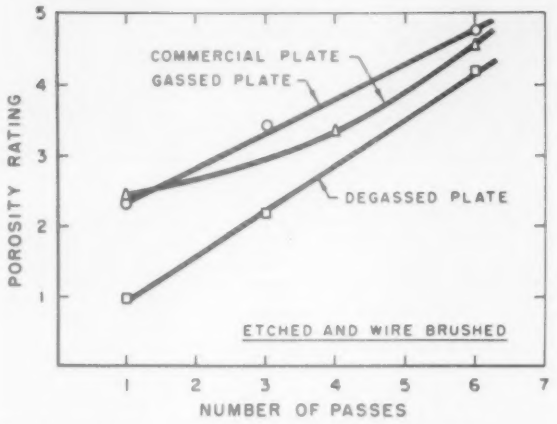

Fig. 4 Porosity in overhead welds in Al-Mg-Si alloys

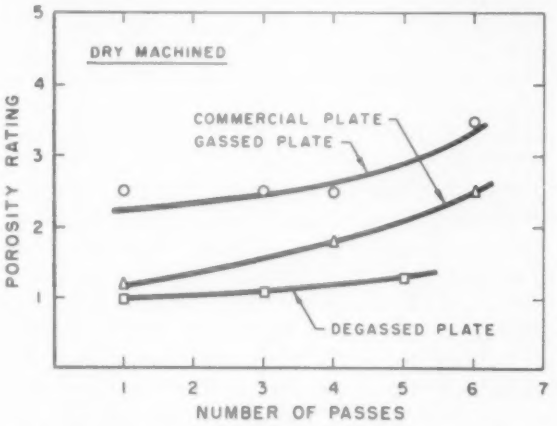

Fig. 5 Porosity in overhead welds in Al-Mg-Si alloys

rinsed, etched in nitric acid, and again rinsed to remove rolling lubricant and other foreign material prior to welding. The plate was wire brushed with a clean, sharp rotary brush immediately prior to welding. These treatments precluded the formation of porosity in the weld caused by surface contaminants.

An argon-shielded tungsten arc was used to make a fusion pass on the underside of the cleaned aluminum plates. Since the argon protected the weld pool from moisture and other sources of hydrogen, any porosity formed in the weld was thought to have been caused by agglomeration of gas in the plate. Multiple-pass welds of this type were made on gassed, degassed and commercial plate of both aluminum-magnesium and aluminum-magnesium-silicon alloys. The amount of porosity was evaluated by radiographic examination and assigned a relative rating, ranging from 1 (sound) to 5 (very porous). Representative radiographs for each of the different ratings are shown in Fig. 2.

Porosity in artificially gassed aluminum alloys increased with the number of passes. It is thought that each pass permitted more of the gas to agglomerate into detectable porosity. Since porosity increased with each pass, it was convenient to plot porosity rating vs. the number of passes for each of the alloys and gas contents.

Overhead fusion welds on degassed 5052 and 5056 plate showed low porosity even after six passes. Artificially gassed 5052 and 5056 alloy plate, on the other hand, gave moderately porous one-pass welds (porosity rating 3) and the porosity rating increased with each subsequent pass. Commercially fabricated plate of 3004, 5052, 5154, 5056 and 5356 alloys all showed low porosity. Figure 3 presents these data as a plot of porosity vs. passes for artificially gassed, degassed and commercially fabricated aluminum-magnesium alloy plate.

Welds in 6061 alloy plate showed the same general relation between porosity and gas content. However, the porosity ratings of gassed, degassed and commercial plate increased markedly with the number of passes (Fig. 4). Magnesium silicide (Mg_2Si) is known to react rapidly with moisture. Absorbed moisture on the surface of aluminum-magnesium-silicon alloy plate may be the cause of the increased porosity. Porosity was substantially reduced for 6061 alloy plates from which 0.020 in. had been dry-machined a short time before welding. As shown in Fig. 5, the porosity was still dependent on the gas content of the plate.

From the results of the overhead welding tests, it has been concluded that while gas in aluminum-magnesium alloy plate can contribute to weld porosity, commercially fabricated plate does not contain sufficient gas to cause substantial porosity. In general, a slightly higher level of porosity can be expected when welding aluminum-magnesium-silicon alloys than when welding aluminum-magnesium alloys.

The Effect of Gas in Electrode on Porosity in Welds

To evaluate the effect of gas in the electrode on porosity, overhead welds were made using both the tungsten-arc and consumable-electrode processes. The overhead tungsten-arc welds were made by filling a groove in 3004 alloy plate.

Greater porosity occurred in welds made with artificially gassed wire than in those made with degassed

Table 1—Porosity of Overhead Tungsten-Arc Welds as a Function of Filler-Wire Alloy and Gas Content

Wire alloy	*Condition*	*Plate alloy*	*Average porosity rating*
No filler	...	3004	1.3
Al-Mg*	Gassed	3004	1.6
Al-Mg*	Degassed	3004	1.3
4043	Gassed	3004	3.4
4043	Degassed	3004	2.1
4043	Commercial	3004	2.5

* Al + 4.25 Mg + 0.1 Cr + 0.1 Mn.

electrodes. Commercially fabricated wire produced welds of a porosity rating nearly as low as degassed wire. For equivalent gas content, the aluminum-magnesium alloy wires gave less porosity than 4043 alloy wire. These results are summarized in Table 1. As was the case for aluminum-alloy plate, commercial aluminum-alloy electrodes did not contain enough gas to make a substantial contribution to porosity.

Overhead consumable-electrode welds were made using several commercial aluminum-magnesium and 4043 alloy electrodes. Welding conditions for the $^3/_{32}$-in. diam electrode were maintained at 27 v, 240 amp, DCRP, 40-ipm travel speed by automatic equipment. Argon shielding was used. Slightly more porosity resulted with 4043 alloy electrode than with aluminum-magnesium alloy electrode. The composition of the plate alloy had no detectable effect upon the porosity of overhead consumable-electrode welds. This appeared to be logical since the surface area and volume of filler wire directly involved in making the weld greatly exceeded that of the plate alloy. Data from the overhead consumable-electrode welds are presented in Table 2.

When sound consumable-electrode overhead welds were remelted with a tungsten arc in the overhead position without adding filler metal, the average porosity rating increased from 2 to 4. This showed that even though consumable-electrode welds were relatively sound radiographically, they did nevertheless contain substantial amounts of gas.

All-weld-metal specimens from consumable-electrode welds contained approximately 1.8 cc H_2/100 g, whereas commercially fabricated wire or plate contains about 0.3 cc H_2/100 g. These gas contents were measured using the technique[3] of heating the metal in a vacuum and determining the amount of evolved hydrogen. The gas content of the weld metal was high even though degassed plate and wire were used. It was assumed, therefore, that hydrogen entered the weld area from some source other than the plate or wire.

Table 2—Porosity of Overhead Consumable-Electrode Welds as a Function of Electrode and Plate Alloy

Electrode alloy	*Condition*	*Plate alloy*	*Average porosity rating*
5154	Commercial	5052	1.7
5356	Commercial	5052	1.5
4043	Commercial	5052	3.0
Al-Mg*	Commercial	1100	2.0+
Al-Mg*	Commercial	3004	2.1+
Al-Mg*	Commercial	5052	1.7+
Al-Mg*	Commercial	5056	1.5+
Al-Mg*	Commercial	6061	2.2+

* 5052, 5154 and 5356.
+ Average for 5052, 5154 and 5356 electrodes.

It was concluded that large amounts of gas can be present in consumable-electrode welds, but that is generally so finely dispersed that it cannot be detected radiographically. In this form, gas in the weld has no known effect upon mechanical properties.

Effect of Welding Conditions and Shielding-Gas Composition on Weld Porosity

Clean, commercially fabricated aluminum plate and wire having been exonerated as causative factors of weld porosity, the bulk of porosity was thought to be caused by atmospheric contamination of the shielding gas. Dowd[4] pointed out the advantages of 65% helium – 35% argon shielding gas for porosity-free welding. The shaded areas in Fig. 6 represent, for $^3/_{32}$-in. diam electrode, the porosity-free range of arc voltage and current for overhead welds in three shielding-gas compositions. Similar diagrams could be plotted for other electrode diameters, with only the ampere scale changing to show equivalent electrode-current densities.

With helium-argon shielding, sound welds are more apt to be deposited over the range of current and voltage conditions encountered in commercial welding than with pure argon. As Dowd pointed out, the helium-argon mixture provides a sound weld under all conditions where it is convenient to deposit a weld bead.

Several explanations for the decrease in porosity occasioned by the use of helium-argon shielding have been proposed During the welding operation, metal flow

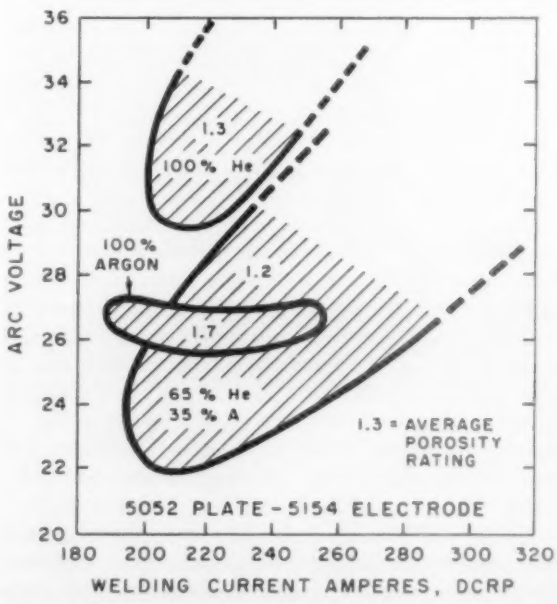

Fig. 6 Current-voltage porosity diagram for overhead consumable-electrode welds with various shielding gases

is better and oxide removal proceeds more satisfactorily than in either helium or argon alone. In addition, the helium-argon atmosphere produces more stable, spray-type metal transfer than either helium or argon alone. With the smoother arc, there is less chance for atmospheric contamination of the shielding gas.

It was not known whether the helium-argon mixture decreased the gas content of the weld or merely dispersed the hydrogen. Overhead consumable-electrode welds were remelted in the overhead position using a tungsten arc. Figure 7 shows the porosity in these welds before and after refusion. The porosity rating of re-fused consumable-electrode welds made in argon increased from 2 to $4^1/_2$. Welds made with argon-helium shielding, on the other hand, increased from 1 to 3. The helium-argon and proper current and voltage conditions, therefore, not only reduced porosity but, in addition, reduced the gas content of the weld bead.

To substantiate this conclusion, gas analyses were conducted on all-weld-metal samples. The gas content of the weld metal taken from a bead deposited in argon showed 2.0 cc H_2/100 g, whereas a sample taken from a weld made in helium-argon showed only 1.3 cc H_2/100 g.

Small additions of chlorine and other halogen gases to the argon for consumable-electrode welding have been proposed to reduce weld porosity. Chlorine from 0.06 to 0.20% by volume was added to shielding gases of argon, helium and helium-argon. In these concentrations, chlorine with argon or helium reduced porosity. However, the beneficial effect was less than that produced by helium-argon. Moreover, chlorine added to helium-argon showed no discernible improvement. Chlorine, even when premixed with argon in a special cylinder, was difficult to handle, caused operator discomfort and corroded welding equipment. Chlorine also left a slight film of aluminum chloride on the cool aluminum adjacent to the weld bead. This film, unless removed, could accelerate corrosion.

Chlorinated hydrocarbon gases such as the freons and geons were added to argon in amounts from 0.05 to 3.0%. It was hoped that the high arc temperature would break down these gases and liberate free chlorine. Their use, however, resulted in a carbonaceous residue that reduced wetting.

Nitrogen, hydrogen, methane, carbon monoxide and carbon dioxide added at 0.01 to 10% to the shielding gas produced black-appearing welds containing inclusions and increased the porosity. Oxygen, in concentrations up to 1%, reduced porosity slightly and increased the penetration. However, more oxide was formed, both at the surface and in the interior of the weld. None of these additions approached the ability of the 65% helium – 35% argon gas mixture to reduce porosity.

Summary

The greatest source of porosity in inert-gas-shielded consumable-electrode welds in aluminum is atmospheric contamination of the shielding gas during welding. Such contamination is especially likely if the arc is unsteady, as when welding with incorrectly adjusted arc voltage or current, and can be minimized by a helium-argon shielding gas.

Excessive gas in aluminum plate or electrode can contribute to porosity. Commercial alloys, however, generally do not contain sufficient gas to make a substantial contribution to porosity.

Aluminum-magnesium alloys give lower weld porosity than aluminum-magnesium-silicon alloys because of their less reactive surfaces.

Oxygen and chlorine additions to argon, while reducing porosity, appear to have disadvantages that make them undesirable for most applications.

Finely dispersed hydrogen has no known effect on the mechanical properties of aluminum-alloy welds. However, inclusions, oxide films and other discontinuities in aluminum-alloy welds can reduce their strength. Methods for reducing these discontinuities are being studied.

No combination of shielding gas or welding technique will produce sound welds on dirty aluminum plate. Oxide and oil films must be removed prior to welding. Clean aluminum, welded using the correct current and voltage, and the proper shielding gas, will give sound consumable-electrode welds in all positions.

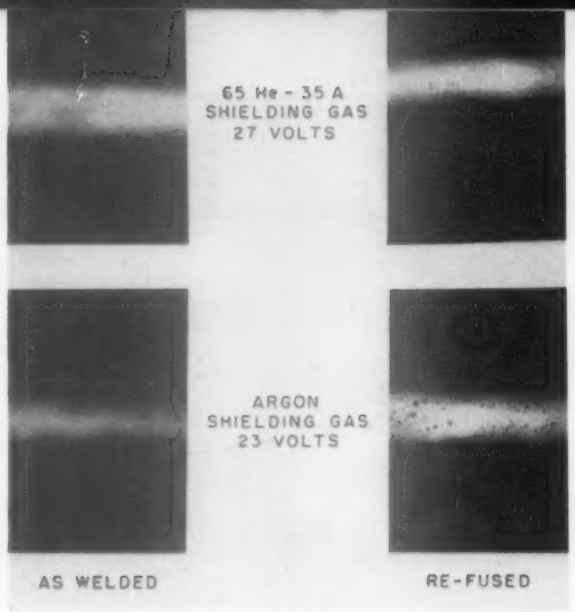

Fig. 7 Porosity in overhead consumable-electrode welds

Acknowledgment

Acknowledgment is made of the work of J. L. Brandt, and J. D. Dowd, G. W. Oyler and M. D. Kiessling. Their contributions appear in many portions of this paper.

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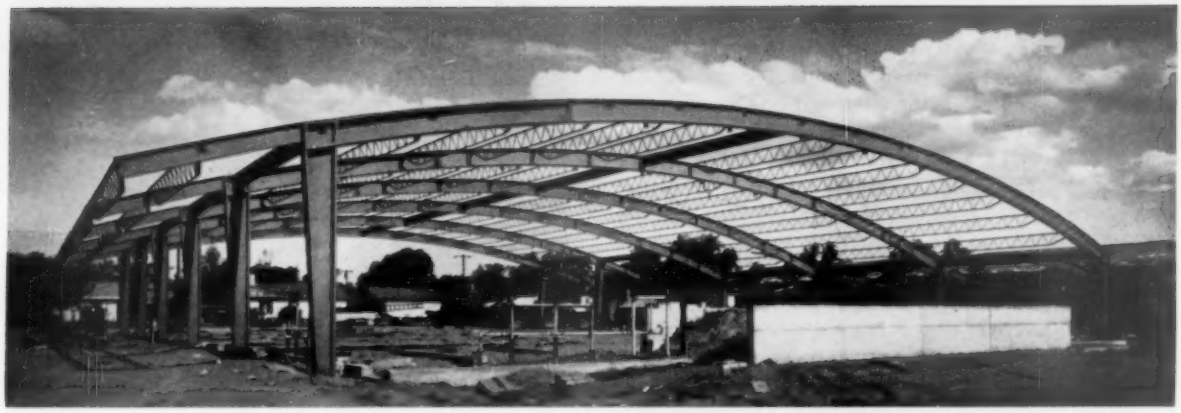


Fig. 1 Six all-welded arches span the main arena of school structure. First four are about 89 ft long and connect at the right to 40-ft arches to form a continuous double span

WIDE-SPAN ARCHES FOR RIGID-FRAME SCHOOL STRUCTURE ARE COMPLETELY ARC WELDED

BY WILLIAM F. FISCHER

Backbone of a new rigid-frame structure at Madison Elementary School No. 6 in Maricopa County, Phoenix, Ariz., is a system of six single-span and double-span fabricated arches. They are spaced on 21-ft centers, the four longer spans being 88 ft $10^3/_4$ in., and 40 ft, respectively; the single spans, 76 ft 8 in. (Fig. 1). This forms three principal arenas—a main auditorium (or cafeteria, if desired) 77 x 89 ft; an adjoining wing, 40 x 63 ft for food preparation; and an end section, 32 x 77 ft (Fig. 6).

Double-span arches overhang supporting columns by 10 ft on the long-span side, 5 ft on the opposite side, to form outside canopies (Fig. 2). The single-span overhang is 10 ft on either side. Columns at the outer ends of the arches have tapered webs of $^1/_2$-in. plate, 18 in. wide at the top and 9 in. at the base (Fig. 3). Inside flange is vertical, while the outer member flares out, both being of $1^3/_4$-in. plate, 12 in. wide.

Center columns of the double spans are of uniform weld-fabricated section, equivalent to an 18 WF 85-lb beam (Fig. 4). Columns are about 13 ft high to the top flange of the arch. The latter is formed to a radius of 150 ft 6 in. on the long spans, bringing the center to 17 ft above floor level. Opposing column base plates are bolted to concrete footings and are joined by 2-in. tie-rods, with a center turnbuckle pulled up tightly before the floor is poured.

William F. Fischer is a welding engineer, The Lincoln Electric Co., Phoenix, Ariz.

The long spans of the double arches are spliced at a point 16 ft from the outer columns and 9 ft from the center supports. The 76-ft 8-in. spans are similarly splice welded 8 ft from the columns. Shorter 40-ft arches are continuous. All are specified as 18 WF 77-lb beams, with a fabricator's option of welding $^{13}/_{16}$-in. flange plates, 9 in. wide, to a $^1/_2$-in. web, $16^1/_2$ in. deep.

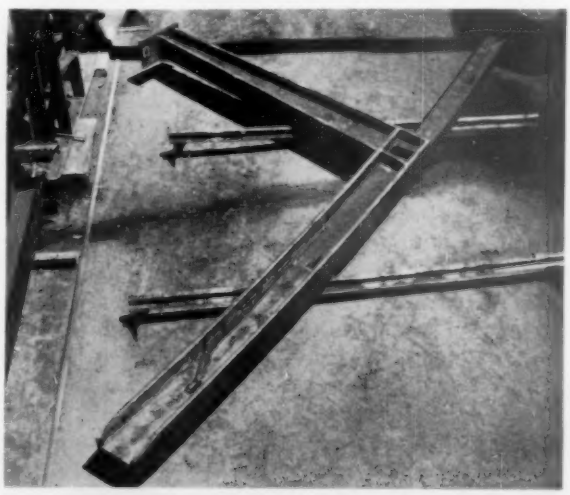


Fig. 2 Outer end of arch and 10-ft overhang beam are welded to tapered columns in the fabricating shop. Note tapered flanges on the arch end at point where connection to main span is made

Columns are tied together laterally by 12 WF 27-lb beams, as are the arches at approximately their centerline. Between these lateral beams are open-truss joists welded to the arches on 6- and 5-ft centers for the shorter arch of the double-span area.

Fig. 3 Two spans for the 89-ft arches are in position for welding at the fabricator's yard. Web is $^1/_2$-in. plate, 18 in. deep; flanges, $^{13}/_{16}$ in., 9 in. wide. Welds are intermittent chain type

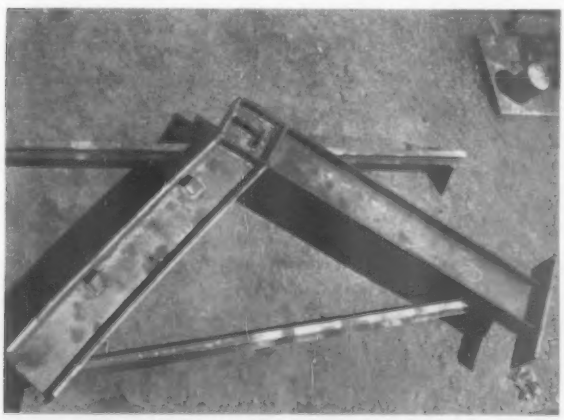


Fig. 4 Center column of double-span arch is of uniform section, with heavy base plate for bolting to foundation pier. Columns are braced by tierods to the bases, making a completely rigid frame

Fig. 5 Detail of column-to-arch connection, showing massive multiple-pass arc welds. Plate ends are double-beveled for full-weld penetration. Plate sections are $1^1/_4$ in. thick

Roof framing is completed by welding bulb tee purlins parallel to the arches. Then, a combination of formboard and 2 in. of poured gypsum is applied.

Included among the reasons that architects Lesher and Mahoney of Phoenix decided on the novel structural system are the continuity of form with other curved-roof structures in the area, minimum waste cubeage with maximum unobstructed inner area and saving in steel. Structural steel aggregated only 80 tons, exclusive of roof joists and purlins, a weight considerably less than would have been required by conventional girder and column construction.

Analysis of stresses in arch frames by classical methods is apt to be rather tedious. The consulting engineer, Walter Riley of Phoenix, developed a modified moment-distribution method which proved practical in the present instance. Thrusts and moments may be calculated quickly with the aid of formulas and a slide rule.*

Manual arc welding of all sections was done in the shops of Acme Steel Co., Phoenix, and also at the erection site. Each of the large-span frames was welded together flat on the ground from which point the arch and columns were raised to position. The short-span arches were welded to columns in the vertical position. From the illustrations, it will be noted that the columns carry a short length of the arch, with flanges tapered 1

* A detailed discussion of the technique was published in the April 1957 issue of the "Journal of the American Concrete Institute," Vol. 28, No. 10.

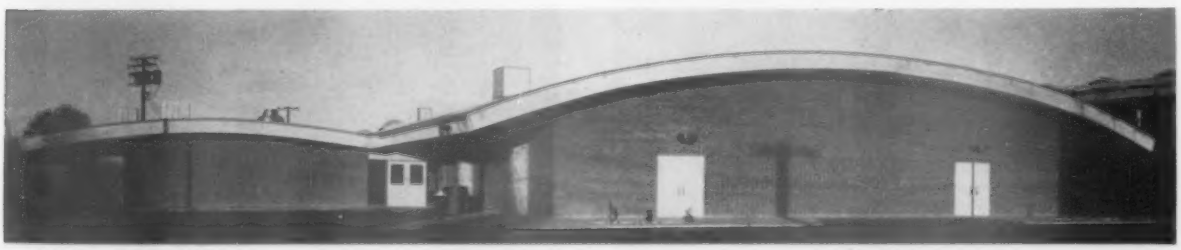


Fig. 6 Complete structure provides three arenas to give flexibility in meeting the eating and assembly needs of Madison Elementary School, Phoenix, Ariz.

ft back of the splice line to match the narrower flange width of the main arch section.

The long arch spans were assembled by intermittent or chain-type fillet welds between webs and flanges, as the elements rested on rails as illustrated. Submerged-arc automatic welding equipment might have been put to profitable use on these long joints, but it was not available at the time. Angle brackets were welded in place along the arch webs to hold the roof joists.

Erection began at the west end of the building by setting up the first 89-ft arch assembly. Then, the other long arches were set up in succession, with struts and joists being filled in as each arch went up. Next, the two 77-ft arches were positioned and, finally, the connecting 40-ft arches.

An accompanying sketch of the arch detail and the column connections indicates how the plate ends were double-beveled for full-weld penetration (Fig. 5). This procedure was followed in all joints transmitting the principal loads.

TUNGSTEN-ARC WELDING RAISES OUTPUT OF ALUMINUM WINDOW FRAMES

Aluminum window frames and doors have won wide approval among home-owners and builders because of their ease of maintenance. Due to an increased demand, manufacturers have sought ways to raise output—and inert-gas tungsten-arc welding has solved their problem.

Trim Slide Window Corp. of Farmingdale, L. I., has used this process to speed substantially production and cut costs—$3.50 per frame. Capital Products Corp. of Mechanicsburg, Pa., is another aluminum frame manufacturer who uses inert-gas tungsten-arc welding to good advantage.

Based on a story by the Linde Co., New York, N. Y.

Frame sides for the aluminum windows are cut to size and then rinsed with hot water. Corner joints to be fabricated are clamped in a jig mounted on a platform to accommodate any size frame. The jig holds the frame firmly in place during welding, and conducts heat from the weld area.

An envelope of inert argon gas surrounds the arc and molten puddle, shielding the weld zone from the atmosphere and preventing weld contamination. No flux is needed in the operation.

With inert-gas tungsten-arc welding, high-quality welds are easily obtainable. The operation is quick and simple—assembly time for a complete frame is only four minutes.

Fig. 1 Welding operator welds one corner of an aluminum window frame

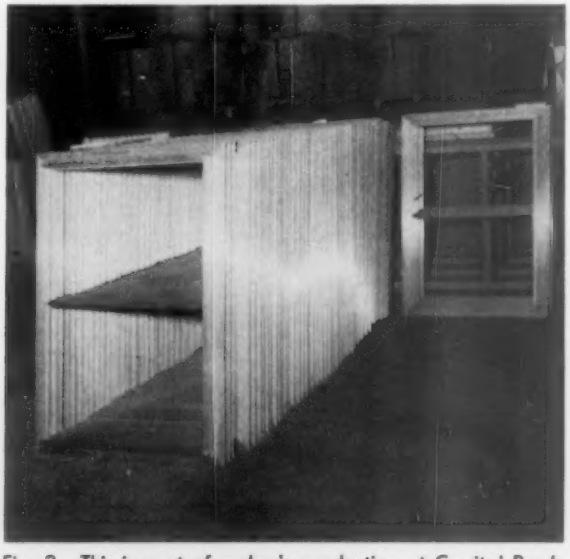


Fig. 2 This is part of a day's production at Capital Products Corp. in Mechanicsburg, Pa.

WELDING BUILDS "TRANSPORTATION CASKS" FOR RADIOACTIVE MATERIALS

BY P. E. WOODWARD

A current project at O. G. Kelley and Co. Boston, Mass., is the fabrication of eight lead-filled "transportation casks" for the shipping of radioactive materials (see Fig. 1). This job requires 13,000 ft of welding by a gas-shielded metal-arc machine welding installation on stainless-clad material. The lead wall and cover of this vault, which has a thickness of $8^3/_4$ in., is homogeneously bonded to the carbon-steel side of the stainless-clad interior and exterior surfaces of the cask which has hundreds of "fins" for heat transfer (see Fig. 2).

Scaffolding erected especially for the welding operation permits use of a platform "elevator" with equipment for making machine welds on the fins at various levels, many of them over four feet long. There are 98 fins on each of the four sides of the cask and specifications call for full penetration welds on $^1/_2$-in. thick material with 45-deg bevels. These welds are made in three passes using 308 stainless filler wire within a shielding gas mixture of argon and helium (see Fig. 3).

P. E. Woodward is Process Engineer for the Air Reduction Sales Co., Boston District.

Fig. 2 Series of stainless fins for heat transfer which have been welded

Fig. 1 Completed transportation cask for shipping radioactive materials

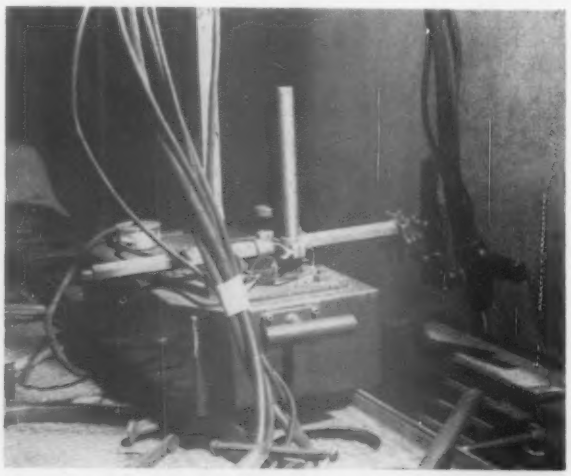


Fig. 3 Welding gun shown in position for machine weld on fin

Society News

Enthusiasm and Optimism Prevail at 39th Annual Meeting

Large crowds attend week-long program at Hotel Statler and Kiel Auditorium in St. Louis

This Monday morning confusion was soon restored to good order by Convention Chairman Dato's gavel in the adjoining Grand Ballroom. It marked the official beginning of our Society's 1958 Annual Spring Meeting

President C. P. Sander welcomes the overflow crowd of members and guests present at the opening session of the St. Louis Meeting. In his address, "Sandy" stressed the importance of welding in this new age of metals

The true spirit of St. Louis welcomed the thousands of visitors who attended the successful 39th Annual Meeting and the 6th Welding Show of the AMERICAN WELDING SOCIETY during the week of April 14th. Registration for the technical sessions reached the official mark of 1389, while close to 8800 individuals passed through the portals of Kiel Auditorium to view the exhibits of 128 companies.

Among those present were many visitors from other areas of the world. Some came from as far away as New South Wales, Australia.

Awards Given At Opening Session

J. E. Dato, convention chairman, officially opened the five-day meeting at the initial session on Monday morning, April 14th, in the Grand Ballroom of the Hotel Statler. A capacity audience later listened to President C. P. Sander discuss welding's important position in this new age of metals.

At this same session, various leaders were honored for their outstanding achievements in the field of welding. Meritorious Certificate Awards were presented to: C. A. Babbitt, T. Embury Jones, L. C. Monroe, A. J. Moses, Herbert Rogers, D. C. Smith, Thomas B. Smith, S. W. Snell, Robert E. Somers, H. S. Swan, Harry Udin, J. F. Wagner and Walter H. Wooding. Three men, namely, O. B. Bowers, G. E. Linnert and I. Morrison, were not present to receive their awards. These men were awarded the certificates in "recognition of their efforts and their contributions to the advancement of welding."

The National Meritorious Certificate Award went to Clarence Jackson, staff engineer, Linde Development Laboratory. Inasmuch as Mr. Jackson was in Europe at the time of the presentation,

the award was accepted on his behalf by Norman Davis. Mr. Jackson was selected "in recognition of his counsel, loyalty and devotion to the affairs of the SOCIETY and his outstanding contributions of time and effort in behalf of the SOCIETY."

Leon C. Bibber, chief research engineer—welding, United States Steel Corp., was made an Honorary Member of the SOCIETY in recognition of "his exceptional accomplishments in the development of the welding art."

Lynn S. Beedle, research associate professor and chairman of the Structural Metals Division at Lehigh University's Fritz Laboratory, and George C. Driscoll, Jr., research instructor, Department of Civil Engineering at the same school, were awarded the A. F. Davis Silver Medal for their paper, "The Plastic Behavior of Structural Members and Frames." This paper was originally published in the June 1957 issue of THE WELDING JOURNAL. Mr. Driscoll was present to accept on behalf of the co-authors.

Perry C. Arnold, chief field welding engineer for the Chicago Bridge and Iron Co., was presented with the J. F. Lincoln Gold Medal for his paper, "Problems Associated with the Welding of T-1 Material," published in the August 1957 issue of THE WELDING JOURNAL and selected by the Committee of Awards for "its originality and value."

R. D. Thomas, Jr., president of the Arcos Corp., was awarded the Samuel Wylie Miller Medal for "meritorious achievement which has contributed conspicuously to the advancement of the art of welding and cutting."

Election of Officers Announced

During the annual business meeting, held as part of the initial session, the election of a new slate of officers was officially announced. Their terms will commence on June 1st.

The officers, as reported in the May issue of THE WELDING JOURNAL are as follows: President, G. O. Hoglund; First Vice-President, Charles I. MacGuffie; Second Vice-President, R. David Thomas, Jr.

Directors-at-Large are: Arthur A. Holzbaur, Donald B. Howard, Clarence E. Jackson and Jack L. York.

Elected as Regional Directors were: District 2, Middle Eastern, Ernest E. Goehringer; District 4, Southeast, Edward C. Miller; District 6, Central, James N. Alcock; District 8, Midwest, Frank G. Singleton; District 10, Western, Francis V. McGinley.

Adams Lecture Impressive

Ernest F. Nippes, professor of metal-

The transfer of leadership is symbolized as President Sander passes the gavel on to President-Elect G. O. Hoglund during the Annual Business Session

(Left) President-Elect Hoglund formally accepts the presidency of AWS at the Monday morning opening session. *(Right)* W. L. Fleischmann, conference chairman of the ASME Coordination Committee, addresses those present on behalf of the American Society of Mechanical Engineers. The ASME Metals Engineering Division participated in the technical program by sponsoring four papers sessions

Second Vice-President-Elect R. David Thomas, Jr. *(right)*, receives the Samuel Wylie Miller Memorial Medal from President Sander in recognition of his contributions to the art of welding and cutting

Leon C. Bibber accepts a certificate enrolling him as an Honorary Member of the Society from President Sander

Ernest F. Nippes *(right)* is presented with the 1958 Adams Lecture certificate by President Sander. Dr. Nippes' paper, "The Weld Heat-Affected Zone," was delivered before the largest audience ever to attend an Adams Lecture

President Sander awards the J. F. Lincoln Gold Medal to Perry C. Arnold for his paper, "Problems Associated with the Welding of T-1 Steel"

George C. Driscoll, Jr., of Lehigh University accepts the A. F. Davis Silver Medal from President Sander. Mr. Driscoll and his co-author, Lynn S. Beedle, won the award for their joint paper, "The Plastic Behavior of Structural Members and Frames"

lurgical engineering and director of welding research at Rensselaer Polytechnic Institute, was the Adams Lecturer at the opening session. He spoke on "The Weld Heat-Affected Zone." The honor of presenting the Adams Lecture is bestowed annually upon an outstanding scientist or engineer who has made a valuable contribution to the field of welding. Dr. Nippes explained that his topic had been prompted by the keen interest exhibited by the welding laboratory at Rensselaer in the effect of weld thermal cycles on the microstructure and mechanical behavior of base metal in the heat-affected zones. He described apparatus which had been developed to permit exact duplication of any weld thermal cycle in a specimen of suitable size for subsequent mechanical testing. Also, he emphasized the advantage of this approach—the ability to create finite volumes of any particular weld heat-affected zone structure at will, this permitting careful study of the microstructural changes produced by welding and correlation of such changes with physical and mechanical behavior.

ASME Cooperates on Sessions

Throughout the remainder of the week, a total of 63 papers was presented at the technical sessions. Some of the papers attracted audiences of close to 400 people.

Seventeen of the technical sessions were held under the sponsorship of the American Welding Society. Coverage was given to such subjects as steel weldability and research; designing for welding; welding arcs and heat flow; resistance welding; aluminum and magnesium; titanium; uranium, titanium and high-nickel alloys; brazing; welded structures; gas-shielded welding; submerged-arc welding; and application, equipment and inspection.

The Metals Engineering Division of the American Society of Mechanical Engineers cooperated with AWS in the sponsorship of four additional technical sessions. These dealt with such topics as strength of welds; mating of structural properties with design; design and material for low-temperature application; and casting weldments.

The opening ASME-sponsored session on Wednesday morning was attended by James N. Landis, president of ASME. Mr. Landis, who is vice president of Bechtel Corp., San Francisco, Calif., noted the fine cooperation between the two societies and expressed a desire for a continued amiable relationship.

This time President Sander is on the receiving end. Past-President J. J. Chyle presents "Sandy" with a certificate and pin entitling him to Life Membership in AWS

E. H. Holder *(left)*, Pascagoula Section, and H. H. Comstock *(center)*, Chicago Section, accept membership awards on behalf of their respective sections from President Sander. During the 1957–58 fiscal year, the Pascagoula Section had the greatest percentage increase in membership, while the Chicago Section showed the largest numerical gain

Meritorious Certificate Awards are proudly displayed by the recipients. Shown in front row are *(left to right)* Harry Udin, C. A. Babbitt, H. S. Swan, President Sander, T. B. Smith, A. J. Moses and D. C. Smith. The top row *(left to right)* consists of T. E. Jones, S. W. Snell, R. E. Somers, Herbert Rogers, J. F. Wagner, L. C. Monroe and W. H. Wooding. Others who won similar honors, but were not present, included O. B. Bowers, G. E. Linnert and I. Morrison

Success Marks Featured Activities

Professor Earl R. Parker, University of California, explained the "Engineering Behavior of Welded Structures" at the Educational Lecture Series presented on Monday and Tuesday afternoons. This activity was under the direct sponsorship of the Educational Activities Committee.

At another meeting sponsored by the Educational Activities Committee, J. H. Humberstone, president of Air Reduction Sales Co., and R. D. Stout, head of Lehigh University's Department of Metallurgical Engineering, spoke on the need for educational expansion and improvement in the welding industry. Additional details are given in a later section of this issue.

Also on Tuesday afternoon, an informal panel discussion was held in Kiel Auditorium on "Practical Shop Operations." Ted Jefferson, editor of *Welding Engineer*, served as chairman of the panel. The latter group consisted of A. E. Adkins, H. Jackson, H. L. McElhoe, P. G. Parks and A. A. Wald.

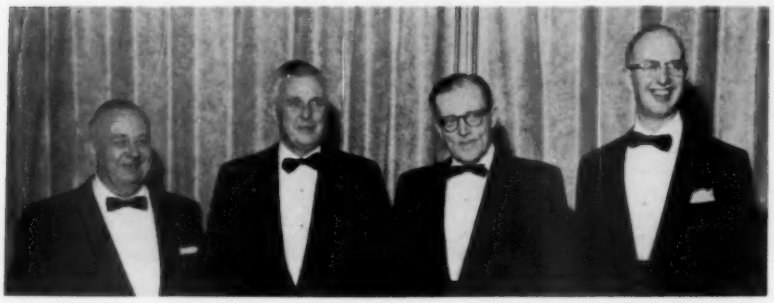
James F. Lincoln, chairman of the board, The Lincoln Electric Co., addressed a full room at the Sustaining Members' luncheon on Thursday. Mr. Lincoln's subject was "How to Meet Today's Needs in Metal Fabrication." Past-President J. J. Chyle presided at this important affair.

Bennett Cerf Speaks at Banquet

Relaxation was in order on Monday evening at the traditional President's Reception. Here the usual, pleasant custom of meeting national officers, staff officers, new friends and the renewal of old acquaintances was enjoyed by some 600 AWS members and guests present. Immediately following the reception, the Annual Banquet, sponsored by the St. Louis Section, was held in the Grand Ballroom. Featured at the affair were two humorists who entertained the large throng in attendance. A. Carl Weber served as toastmaster on this occasion to the delight of the diners. He was followed by the nationally known Bennett Cerf, who deviated from his talk of "Changing Styles in American Humor" long enough to note that "following Colonel Weber was like following Bob Hope." Mr. Cerf, publisher of Random House and TV panelist on "What's My Line," pointed out the worth-while effect a number of American comedians have made on the international scene.

Large Crowds Attend Plant Tours

Nearly 400 persons took advantage of the excellent plant tours arranged by the St. Louis Section. The Wednesday group journeyed to the A. O. Smith Corp. plant in Granite City, Ill., to see the mass-production assembly line of the new all-welded Chevrolet automobile body frame. The Midwest Piping Co. plant, St. Louis, Mo., major fabricators of pressure and process piping for all industrial applications, was visited on Thursday morning. Here, the AWS visitors witnessed, among other things, the fabrication of a low-alloy steel piping with an OD of 22 in. and a wall thickness of 4 in.



"Sandy" poses with the top three elected officers of AWS who will guide the destinies of our Society during the 1958–59 fiscal year. Next to our outgoing president are *(left to right)* President-Elect Hoglund, First Vice-President-Elect MacGuffie and Second Vice-President-Elect Thomas

Hand clasps and smiles are the "order of the evening" as the National Officers meet their fellow men of welding in the receiving line at the President's Reception. Gala event was held in the Statler's St. Louis Room on Monday evening

Bennett "What's My Line" Cerf, principal speaker at the Annual Banquet, seems to be having his troubles keeping up with National Secretary F. L. Plummer, President Sander and President-Elect Hoglund

Ladies' Program Excels

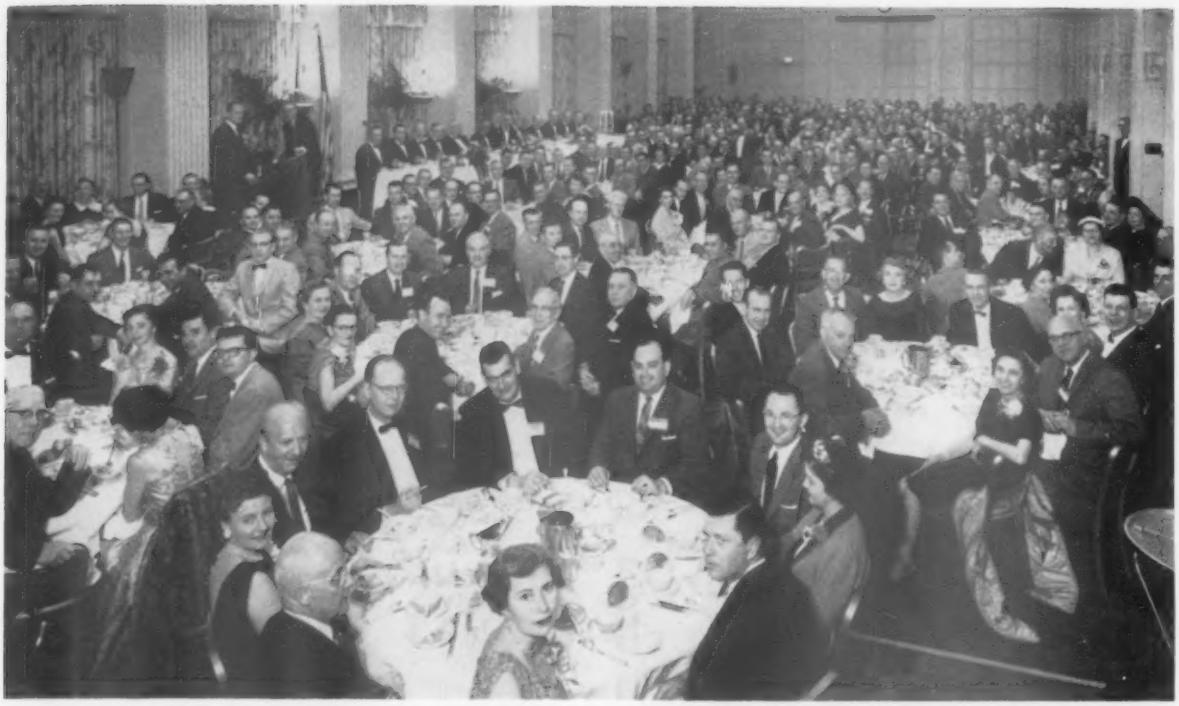
One hundred and eleven ladies registered for the successful ladies' program. During a week replete with luncheons, coffee hours and teas, the fairer sex found time to visit such St. Louis landmarks as the Jewel Box floral display, the Mississippi riverfront and levee, August Busch's baronial estate and even Stan Musial's Restaurant.

Welding Show Opens

President-Elect G. O. Hoglund climaxed the colorful ceremony at Kiel Auditorium on Tuesday morning by expertly cutting the aluminum chain, marking the official opening of the 6th Annual Welding Show. Valued at $2,500,000, the displays in the auditorium covered more than 33,000 sq ft of floor space. Official registrations for the show totaled 8743. Not included in this tally were a thousand or more others from the area, namely, students from the city's universities, vocational, trade and high schools. The continuous flow of interested individuals toured the exhibits to note the latest advances in the art of welding. Many of the booths contained live exhibits, encompassing practically every facet of welding and its allied processes. One corner of the exhibit hall was devoted to welded products of manufacturers in the St. Louis area.

●

The success of the 1958 Annual Spring Meeting and the 6th Welding Show would not have been so great were it not for the tireless efforts expended and the sincere cooperation given by the members of the St. Louis Section. It is only fitting to acknowledge the work of the following committee chairmen: H. M. Gillerman, chairman of the arrangements committee; D. S. Lewis, dinner; E. G. Burrow, hospitality; H. W. Castle, housing; N. Nyberg, ladies' entertainment; R. R. Fayer, meeting sessions; R. G. Alm, personnel; E. G. Mathae, plant tours; G. O. Bland, president's reception; J. W. Punch, publicity; T. J. Ryan, Jr., signs; L. J. Winkeler, technical; H. G. Cave, ticket sales; R. A. Near, transportation; and I. L. Polick, welded products. Credit is also in order for P. C. Enslin, chairman of the St. Louis Section, and L. W. Morrell, St. Louis representative for ASME.



A partial view of the banquet, effectively organized by the St. Louis Section, catches the diners well aware between courses in the Statler's Grand Ballroom on Monday evening

Presidential Address

By C. P. SANDER

President, 1957–58, American Welding Society

On this opening day of our Annual Meeting of the AMERICAN WELDING SOCIETY in St. Louis located near the center of our country, I bring you greetings from the four corners and the WELDING SOCIETY Sections of those areas, most of whom are represented here today. We have been looking forward to this week with anticipation and I am certain that we shall not be disappointed. We appreciate your efforts and are glad to have been invited here.

The AMERICAN WELDING SOCIETY now has 79 active Sections of which Providence, R. I. is the newest one with over one hundred thirty members. We have requests for 3 additional new sections on which organizational work is now under way. Our membership of nearly 13,000 has been maintained even though we increased dues the past year as well as experiencing a recession of business in general the last few months.

Being located on the far West Coast, I have spent much time in air travel trying to help fulfill the duties expected of one as President of your SOCIETY. To me this has been a busy and interesting year. I have visited as many Sections and functions as time would allow, in most places having our National Secretary as a team-mate. The welcomes extended and the courtesies shown, have been an inspiration that shall not soon be forgotten.

I wish to give credit and voice appreciation to the other officers and directors of the AMERICAN WELDING SOCIETY for their fine cooperative attitude and efforts on behalf of our SOCIETY activities.

I particularly desire to express recognition on behalf of the SOCIETY to the fine way in which Fred L. Plummer has taken over the responsibilities as our National Secretary. He has had the whole-hearted and loyal support of our fine headquarters staff and together they have shown real teamwork and progress.

Our Treasurer's report will show that we have operated this year within the budget and maintained our reserves intact.

The Technical Activities functions of our SOCIETY have been well handled. The numerous Technical Committees have been active with scores of meetings and sessions held. Numerous publications and code revisions have been accomplished. Revised pricing and discount policies for AWS publications have been devised with a view to possibly making this activity of our SOCIETY self-supporting financially.

If you take time to review the report of the Handbook Committee you will find that our first Section of the new WELDING HANDBOOK has received an excellent reception. The second section is well on its way for publication this fall as scheduled.

Have you noticed the new features of our WELDING JOURNAL? This publication seems to improve each year. The latest feature includes International Welding News, a systematic coverage that will help keep our members informed on important technical articles on welding in foreign language publications. This should provide interesting and valuable information and help keep us abreast of new welding fabrication advances and in research on physical, mechanical and metallurgical subjects.

This is the first year for a long time that we did not hold a National fall meeting. A committee has been appointed with a view of ascertaining whether or not a fall meeting of some kind is desirable and to make recom-

The ladies discuss the day's schedule during their customary coffee hour in the Daniel Boone Room. The full art of conversation is well illustrated here

Turnouts of this size were not unusual at the technical papers sessions. Evidence of the interest was also noted in the active discussions which followed each paper

(Above, left) The authors' breakfast on Wednesday morning included a head table of hungry dignitaries. Shown *(left to right)* are R. R. Fayer, local chairman of meeting sessions, and H. R. Elfvin, session supervisor, both busy eating; Session Chairman J. J. B. Rutherford, and ASME National President James N. Landis locked in conversation; President Sander; National Secretary Plummer; ASME Session Coordinator Fleischmann; and B. E. Rossi, editor of *The Welding Journal*. *(Right)* President Landis of ASME is introduced by "Sandy" to the large audience at the Wednesday morning session on design and material for low-temperature application

mendations concerning the scope and type of meeting if desired.

President Eisenhower in his address a few months ago to the American people on "Science and Security" stressed the long term importance of education in maintaining our national security. By emphasizing the responsibility of each community and organization to help provide rigorous science and mathematics training to potential scientists and engineers, the President challenges educators and scientists alike.

Our organization being classed as a technical society has been cooperative and extended offers of assistance to further the use and knowledge of welding and its applications including technical data with recommendations to National Research Council, the Atomic Energy Commission, Welding Research Council and to the other Engineering and Technical Societies. Our officers and members have attended and given technical talks to welding conferences and technical sessions at a number of our Universities, Institutes and Colleges during this past year.

In this connection I wish to focus your attention to our Educational Activities headed up by an active Committee which is sponsoring a program potentially having far reaching effects towards developing new educational courses of in-plant training, college training and research. These new stepped-up activities of our Educational Activities Committee and its advisory group deserve your real support. We acknowledge the real efforts being made in this direction by many educators and schools of learning.

Numerous sections are now sponsoring scholarships for deserving engineering students who are keenly interested in welding as a future vocation. Real welding engineers and technicians are greatly in demand and are destined to receive more recognition than most of us at present realize. Many of our sections have held welding conferences, training courses, student nights and welding symposiums in addition to their regular technical meetings with technical papers on timely subjects.

Welding has become an integral part of the American way of life in a very short span of years. Its use is so extensive today it would be difficult to specify all the items and it would require considerable time to try and enumerate them. You are undoubtedly aware of a great many of these applications and I shall simply say that today activity in welding is becoming increasingly more universal. As you travel around our country as I have, you are more cognizant of this genuine interest being displayed by industry and others towards the further use of welding. Well trained welding mechanics and technicians are as much in demand as are welding engineers.

Welding is not only a primary tool of the trade for fabrication and maintenance, but also a primary means by which new basic designs and functions of new ideas can be realized and accomplished. Today we acknowledge at least 37 basic welding processes from miniature spot welds to butt seam welds 10 in. or over in thickness with additional designs and ideas in the research and development stages. Our challenge is ever changing with seemingly no end in sight. Man's ingenuity has a wonder-

Harry Cave *(third from right)* of the St. Louis Section packs them into the buses for their tour of the A. O. Smith Corp. plant in Granite City, Ill. This group is also said to have toured another plant on the same day—the Anheuser-Busch brewery

Policy decisions are discussed during the Board of Directors' meeting on Thursday morning in the New York Room of the Hotel Statler

(Above, left) James F. Lincoln was the principal speaker at the Sustaining Members Luncheon. His hard-hitting address was entitled, "How to Meet Today's Needs in Metal Fabrication." Seated at the head table are *(left to right)* National Secretary Plummer, President Sander, Mr. Lincoln, Past-President Chyle, President-Elect Hoglund and H. M. Gillerman, chairman of the St. Louis Arrangements Committee. *(Right)* President-Elect Hoglund, with face hidden behind the mask, cuts the aluminum chain in the tradition of an old pro at the Kiel Auditorium on Thursday morning. It symbolized the official opening of the 6th Welding Show

ful opportunity to come forth with new methods, new processes, new technical data and experiences that will further integrate welding into more industry and avenues of use as well as improve the current processes. Together we read a great deal with reference to the atomic age, supersonic age or interplanetary age. Someone has said "Are these not really phases of the age of metals?" Our way of life depends on metals and that dependency is basic. Our ability to join metals by welding is rated so highly that the first question asked when a new alloy or metal is developed is "can it be welded?" Much research goes into the picture to accomplish this fact.

A nuclear engineering survey at the University of California states that as technology becomes more complex, each major development permits fewer years for industrial adoption. There was a century for technicians to grow up with steam and for industry to learn its uses. With electricity this time was cut nearly in half, but industry could still train men by usual methods.

Mass production has been with us less

Enthusiastic interest was displayed during the three-day 6th Annual Welding Show in the Kiel Auditorium. The booths, well staffed with technical personnel, housed many live exhibits and were the sites for numerous problem-solving conferences

than forty years and we are still discovering what can be done with its techniques. This is the fourteenth year of the atomic age. Nuclear power is a reality. Radioactive fuels and isotopes are on hand and only lack of knowledge of the field holds industry back from a myriad of profit-making applications.

In the building of nuclear power plants, guided missiles, rockets and space projectiles, the use of welding is paramount to successful fabrication and performance. This program is being accelerated and we need to keep abreast of these requirements to industry. Guided missiles, rockets and their component parts demand close tolerance precision work.

Our welding processes can be tooled up to meet these requirements as well as meet the strength and temperature requirements desired. Improved quality for consistently good results and reduced costs through faster production is a constant goal that is also being realized. By the use of welding, progress is a fact and not only a motto. You get real results if you put forth reasonable effort.

They say business is experiencing a recession. A slowing up in business may readily be the means of directing more firms and industries to ascertain the potential cost savings and end product results that the use of welding can accomplish for them as it has for many of us. I say this as one who has spent the last 30 years directly in the production and construction field. With stepped up activities in all fields pertaining to research and development in industry, welding has not only won a permanent place in our economic life, but will continue to advance and contribute a great deal to progress.

However, AWS still has a challenge to further popularize welding as well as reassuring the public of its full values. As members of the AMERICAN WELDING SOCIETY we should maintain a keen interest in and enthusiasm for our welding activities with a sincere desire to further the understanding and use of welding. We should continue to promote in-plant and extension training courses for welders and technicians; encourage student chapters and foster educational courses for fuller recognition of welding in the engineering field. We are confident that the outlook for welding forbodes a bright and successful future.

It has been a pleasure to have had the opportunity to work with you for this cause this past year. I appreciate all of your many efforts and courtesies. I intend to continue an active interest in this SOCIETY.

Thank you one and all.

Address To Sustaining Members

By JAMES F. LINCOLN

How to Meet Today's Needs in Metal Fabrication

At a time of business slump it might be well for the welding industry to take a look at the future. Welding has made far less progress than it should have made. Most buildings and bridges still are riveted. Some sixteen million tons of castings, both steel and iron, still are made each year, of which at least 75% would be redesigned as weldments with a saving of at least 50% of the present cost.

Other methods of joining metals, such as bolting and the elimination of metal entirely by the use of prestressed concrete, have made tremendous strides in the past few years. It is hard to understand why a process which inherently is so very much cheaper, more reliable and more easily applied, should not take its proper place in its field. The reason is not hard to find. Welding has been continually put under suspicion by those who should have been most intelligent in its application.

The tests which are specified for a welded joint cannot be passed by any other commercial method of joining metals. No riveted or bolted joint could even approach the standards specified for welds and which welds must pass in order to be accepted.

Porosity and undercut, so-called, such as commercially found, are treated entirely differently. Such so-called defects are accepted without question in a riveted or bolted joint when many times greater than found in the usual welded joint. Such defects are rejected in a welded joint, however. The methods used for the discovery of porosity by the X-ray process also usually costs more than the total cost of welding.

The redesign of castings to weldments is now generally done by copying the shape and section of the casting in spite of the fact that the steel which replaces the cast iron is four times stronger and two and a half times as stiff as the cast iron it replaces.

The design of structures in general follows the same approach as was true a generation ago. Since rivets were used then, rivets are used now, in spite of the fact that a saving in buildings and bridges of at least 25% can be made if the structure is properly designed for welding rather than riveting or bolting.

We also have the policy by the people who make up structural-steel sections to continue to use rivets because they have the machinery and the experience which they do not want to discard. Because of all these lacks, the economy has paid billions of dollars in additional costs for its products.

The great opportunity that the AMERICAN WELDING SOCIETY faces is to eliminate the handicaps which have so far kept welding from its proper place in the economy. We should be dealing in our engineering papers with redesign of castings, redesign of bridges and buildings and the application of hard-surfacing material.

There is little need at this time for scholarly dissertations on details which have little practical application. It is of small benefit to the economy to discuss the action of a welded joint at its breaking load when it is used at less than one-quarter of these stresses in actual service.

James F. Lincoln is chairman of the board, The Lincoln Electric Co. His address was presented at the Sustaining Members' Luncheon in St. Louis on April 17, 1958.

EDUCATIONAL ACTIVITIES

AWS Educational Groups Hear Addresses by Humberstone, Stout and Parker

The educational open meeting on Tuesday, April 15th, at St. Louis, as part of the 39th AWS Annual Spring Meeting, attracted a near-capacity audience. Many of the educational representatives of the sections were present.

T. Embury Jones, with his co-chairman Roy McCauley, opened the meeting in the absence of Clarence E. Jackson, chairman of the Educational Activities Committee. Mr. Jackson was detained in Europe.

The purpose of the meeting was to determine how the educational committees of the AWS could help the local sections and how even greater participation from the sections could be obtained. A report of the objectives and accomplishments of the committees acquainted the section representatives present with an over-all picture of the activities and enabled them to judge where they could cooperate.

Mr. Jones mentioned the purpose and the general form the meeting would take. He then went on to explain how the newly activated education committees came into being and the strides they had taken in two years.

An Approach to Welding Education

J. H. Humberstone, president of Air Reduction Sales Co., and a past president of AWS, gave the opening address. He spoke of the need for increased educational activity in the welding industry and explained how education must of necessity be geared to technical progress. He commented on the appalling ignorance of even well-educated people upon all aspects of welding.

"Welding today," said Mr. Humberstone, "has reached—has earned—a position of *confidence*. I believe that welding—the acceptance of it and the confidence in it—has grown *because* of the stringent requirements imposed on it by those who live with welding problems. There have been less failures *along the way* to our present position because of tight codes and specifications as well as severe inspection practices. . . .

"By the same token, I believe that today and after all of these years of experience and education we should be able to take certain things for granted. We have earned the right not to have to prove everything that can't be seen with the naked eye. We *know* that the necessary strength is there. We *know* that the service requirements are easily met in run of mill weldments. Excellent results with welding are uniformly routine in large areas of what is becoming, or already is, standard practice. *Now* we should shake off some of the excessive caution in these areas, some of the unreasonable demands and red-tape procedures and so simplify and ease our specification requirements. However I still believe that the *pioneering areas* of welding progress should continue to get the same thorough-going analyses for procedures, codes, specifications and inspection practices and tests.

"To further illustrate my point, I have recently had occasion to investigate metal-to-metal bonding with plastic cements. And I was reminded, while listening to the reports of tests and results, of the position of welding back in the early days—twenty-five, thirty years ago. A simple question, and a very revealing one, repeatedly occurs in connection with the use of plastic cement in the bonding of metals: 'How do you *know* you have a satisfactory joint?'

"This is an obvious, honest and *proper lack of confidence*. . .resulting from lack of experience and education. This new method of bonding will certainly find its rightful place in the fabricating industries, but it, too, as was true with welding, will have to earn that place, earn the confidence which we of the welding industry now are in a position to enjoy and exploit for the benefit of industry and society in general. It will have to go through the same growing pains, proceeding cautiously, policing itself perhaps more severely than absolutely necessary, establish procedures, codes, specifications and inspection practices, and earn its way to the prominent position it will—I predict—enjoy perhaps ten, twenty or thirty years from now. It will be through educational processes that this will be accomplished and unless *we* continue to educate we will *not* profit by getting certain facts taken for granted in connection with welding, thereby laying the groundwork for the *elimination* of unnecessary restrictions.

"Welding has won its spurs. So we have a lot to talk about and we can do it with a great deal of confidence. That is our message. That is *why* we must educate, and the ways in which we can do the educating are many."

The speaker went on to outline the various approaches that were being made to further welding education and advocated welding symposiums as an

At the Educational Activities Committee meeting on April 15th in St. Louis, Past-President J. H. Humberstone told a large, attentive audience that the need for increased educational activity is determined by the progress made in the welding industry

Robert D. Stout addressed the same group moments later, urging greater educational activity in the field of welding metallurgy. Dr. Stout stated that the sections were the logical groups to conduct such programs

President Sander presents the Educational Lecture Series Certificate to Earl R. Parker. Professor Parker's paper, "Engineering Behavior of Welded Structures," was delivered in two parts on Monday and Tuesday afternoons

excellent means of disseminating welding knowledge. Another practical area of education he favored was that of clinics, demonstrations and open house shows.

In his closing remarks he suggested that satisfaction was the result of ignorance, the complacent attitude of the uneducated. It was his opinion that we can never be satisfied in this country until ample opportunity is being offered either the educator or those to be educated.

Committee Reports

After the opening address, the chairman of each committee was asked to give a brief report on his committee's activities, what had been accomplished and what was in preparation. These reports are not being given in detail since they appeared in the "Educational Activities" column last month.

Section Activities

When the reports had been concluded, a talk was given by R. D. Stout, professor of Metallurgy, Lehigh University. Dr. Stout, who has taken a very active interest in his local section, felt that members look to their sections for their education, the technical sessions at the monthly meetings and the educational lectures during the spring and fall supplying many of their needs. He gave some very sound advice as to the types of programs required. In each area one or more industries predominate. Consequently, the greatest interest locally will center around these industries and their welding operations. Programs slanted to local needs are likely to be popular and well attended.

He suggested that metallurgy always creates a strong interest, although it is better to keep the subject general. His experience had been that interest waned when details were discussed. The broad field of metallurgy seemed to give members the background they needed, whereas the actual details interested a very small percentage of the audience.

Professor Stout gave some excellent practical advice. He suggested:

1. Choose speakers who can stimulate a question-and-answer period.
2. Tailor your talks to your audience.
3. To publicize a subject, such as metallurgy, invite students from the high schools. Have a display of samples and sufficient members available to discuss the samples with the students.
4. Hold demonstration meetings and do not limit your audience to members. Invite the general public too.

Finally, the speaker advised section chairmen to examine their own problems before choosing a subject. In providing a solution to their own difficulties they would solve many of their members' problems.

The last hour of the meeting was devoted to a question-and-answer period. Full advantage was taken of the opportunity, and, had time permitted, the meeting could have lasted well into the afternoon.

The educational representative from Baton Rouge Section gave an interesting description of how his section had developed its first educational program. So many desired to attend that they had to close enrollments when 160 had signed for the course. It was a most gratifying response, and a similar series will be held next year. The entire lecture series had been printed and a limited number of copies are available. Free copies of this series can be obtained by writing to Paul Walmsley, 1266 Stevens Ave., Baton Rouge, La.

Many opinions were voiced and many questions raised. Some of the statements were controversial and received an almost immediate answer from the floor. The meeting was adjourned at 12:30.

The general opinion indicated that the open meeting had been well worth while. Delegates from AWS sections said they had learned much of value and were in favor of the national educational program.

Educational Lecture Series

Each year at the national meeting the Educational Activities Committee schedules an educational lecture by an outstanding authority. This year, Earl R. Parker spoke on the subject of "Engineering Behavior of Welded Structures."

Professor Parker is an acknowledged authority on the subject. Professor of Metallurgy at the University of California, he has been with the university since 1944. His special field of research is in the mechanical behavior of materials, particularly at high temperatures.

Part I of Professor Parker's lecture was given on Monday afternoon. Part II was continued on Tuesday evening. At that session, President Sander presented Professor Parker with the Educational Lecture Series certificate.

JOIN NOW!

If you are interested in better welding, lower fabrication costs and increased productivity, you will gain from investment in AWS Membership. You can learn how to join by writing AMERICAN WELDING SOCIETY, 33 West 39th Street, New York 18, N. Y.

THINGS YOU SHOULD KNOW

(That Happened in April)

● Early April days were filled with preparations for the 39th Annual Meeting and 6th Welding Exposition. Conferences were held with Exposition Manager Bob Kenworthy and with publicity agent Ed Grief and finally a staff meeting of the eight members who traveled to St. Louis to direct the varied activities. Agendas were prepared for meetings of the Board of Directors, the Technical Council and several important committees. Medals and certificates were assembled for the various awards presented at the opening session of the meeting. Annual reports were written.

● Other activities included a meeting of officials of the Pressure Vessel Research Group to plan their annual meeting which will be held next September; a meeting of representatives of all societies and other groups affiliated with the American Standards Association to consider both domestic and international problems encountered in this broad field of activities; a conference with representatives of Bankers Trust Co. concerning the investment of SOCIETY reserve and contingent funds; and discussions dealing with the new United Engineering Center to be constructed in New York.

● On April 9th Staff Members Mooney and Krisman headed for St. Louis to check headquarter hotel arrangements. Later they were followed by Messrs. Chodrow, Fenton, Irving, Phillips, Rossi and your Secretary, all joining national officers including President Sander and President-Elect Hoglund and a large group of St. Louis representatives led by Section Chairman Enslin and Arrangements Chairman Gillerman at the arrangements committee luncheon held Sunday, April 13th.

● Exposition, technical sessions, education lectures, the Adams Lecture, the president's address, the informal panel discussion, the annual business meeting, the presentation of awards, the President's Reception, the annual banquet, the special educational conference, the plant tours, the full ladies' program—all interesting, informative and eminently successful—are described elsewhere in this issue.

● Other equally important activities included the authors' breakfasts at which fifty or more people met each morning to get acquainted, coordinate activities and discuss technical problems of mutual interest; the various district breakfasts and luncheons where district and section officers met to discuss section problems and activities; the luncheon and dinner meetings of special committees and other groups including RWMA, WRC, PVRC, OSU Alumni, Sustaining Members and university professors; the Section Officer's Meeting; the many operating committee meetings including Exposition, Manufacturers, Organization Structure, Welder Registration and Certification, Membership, Member Classes, Reserve Funds, Nominating, Technical Council and Board of Directors; several AWS, PVRC and at least five WRC technical committee meetings.

● Attendance at meetings and at the exposition was excellent. Many exhibitors commented upon the high caliber of those who visited the exposition during the three days following the opening ceremony which was attended by top officials of St. Louis including R. K. Bennett (personally representing Mayor R. R. Tucker), Director of Public Safety Sestric, Director of Public Utilities Mallory, Fire Marshall Mullen and Assistant Trantina, President of Convention Bureau Bryan, Chief of Auditorium Commission Maginn and Auditorium Manager Gualdoni. President-Elect Hoglund cut an aluminum chain using a gas-shielded arc process during the ceremony over which President Sander presided.

● President Landis of the ASME attended the authors' breakfast on April 16th and joined President Sander, President-Elect Hoglund and your Secretary for lunch following the morning technical session sponsored jointly by AWS and ASME. This was one of four such sessions planned by a group under the leadership of Walter Fleischmann, who officially represented ASME at the opening session and the banquet, and in the receiving line at the President's Reception.

● Past-Presidents Humberstone and Chyle were active participants together with national officers MacGuffie, Thomas and Rockefeller, in assisting President Sander and President-Elect Hoglund, who faithfully completed exceptionally heavy schedules beginning early and lasting through the evening of each day. Convention Chairman Dato called to order and closed the opening session on April 14th.

● The Board of Directors approved the recommendations of a special task committee to hold a fall meeting in late September or early October of 1959. The 1959 April meeting and exposition will be held in Chicago with the Hotel Sherman as headquarters, and the 1960

AWS DIRECTORS-AT-LARGE

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For more details, circle No. 7 on Reader Information Card

April meeting and exposition in Los Angeles with the Biltmore Hotel as headquarters.

● Returning to the Hotel Statler following dinner on Friday evening after the close of the meeting, President and Mrs. Sander were given the sad news that Mr. Sander's brother had died while traveling on a train near Great Falls, Mont.

● On April 21st in New York, Charles Kandel, president of Craftsweld Equipment Corp. and a past chairman and active supporter of the New York Metropolitan Section of AWS, died. Your Secretary and other staff members attended his funeral on April 23rd.

● The following day the funeral of George V. Slottman, vice president and director of research and engineering of Air Reduction Co., was held at the Church of the Ascension in downtown New York. Dr. Slottman had served on several important AWS committees and had contributed significantly to the success of our Society.

● On April 25th your Secretary and Mrs. Plummer joined President Sander, President-Elect Hoglund, District No. 3 Director Miller and Mrs. Miller at the twenty-first annual Tri-State Dinner and Ladies' Night of the AWS Pittsburgh Section. Chairman Doty presided at the usual delightful event with an excellent dinner following a friendly cocktail period. W. H. Upson (famed for his *Saturday Evening Post* "earthworm tractor stories") gave his humorous dissertation on "Ergophobia" prior to the distribution of the large collection of expensive door prizes. Chairman-Elect Cable, Secretary Minnotte and Prize Committee Chairman Weber participated in the program which was thoroughly enjoyed by more than 400 members and guests.

● Part of April 28th was devoted to the second of two conferences with Society Attorney Holloway considering the possibility of simplifying the Society By-Laws which have become excessively detailed, complicated and lengthy. Even a minor change such as the forming of a standing committee requires two actions by the Board of Directors, publication of the proposed change in The Welding Journal and finally a letter ballot by the entire membership of the Society. The total cost of making such a change can easily exceed one thousand dollars. It is hoped that a set of rules of procedure can be prepared covering routine activities approved by the Board of Directors and that the By-Laws can be simplified to cover only those matters of direct concern to all members of the Society.

● The last two days of the month were largely devoted to meetings of the Materials, Fabrication and Design Divisions, and the Executive Committee of

Chicago is Next!

The 40th National Meeting of the American Welding Society will be held in Chicago during the week of April 6th.

the PVRC, together with several task and project subcommittees. These groups plan and direct research activities, mostly dealing with welding problems, costing about one quarter of a million dollars each year. These activities, as well as all others of the Welding Research Council, are closely coordinated with AWS activities and most results are published in the Research Supplement of THE WELDING JOURNAL.

● First Vice-President-Elect MacGuffie spent the afternoon of April 29th with your Secretary discussing investment policies, possible professional investment counsels, information program and other 1958–59 activities.

● It is rumored that Technical Secretary Ed Fenton may be proudly, and with proper engineering efficiency, passing out cigars about the time you see this in print in June.

Fred L. Plummer

New Supporting Member

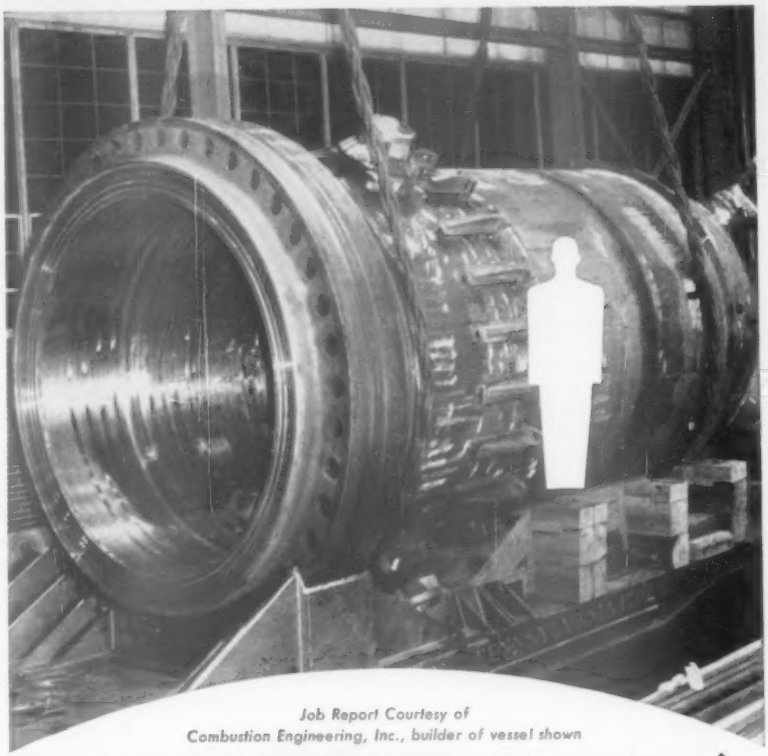
An application has been received from the Oregon Technical Institute, Oretech Branch, Klamath Falls, Ore., admitting the educational group to a Supporting Company membership status in the AMERICAN WELDING SOCIETY. The enrollment became effective on May 1, 1958.

The Institute is also in the final stages of organizing an AWS student chapter.

1958 SPRING MEETING ABSTRACTS AVAILABLE

Complete sets of abstracts of the papers presented at the 1958 AWS Annual Spring Meeting in St. Louis, Mo., are now available at $2.00 per copy. Address your order to American Welding Society, 33 West 39th Street, New York 18, N.Y.

This WELDED nuclear pressure vessel holds a practical idea for you



Job Report Courtesy of Combustion Engineering, Inc., builder of vessel shown

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In nuclear installations where radio activity makes weld failure dangerous to personnel and can cause indefinite shutdown, sound corrosion resistant welds are of utmost importance. To inhibit corrosion, portions of the 9 ft. dia. interior of this 33 ft. reactor were overlaid with ¼ in. of 308L weld metal. Submerged arc welding with ARCOSITE S4 flux was used for the job. The girth and longitudinal joints of the low alloy steel plates were also submerged arc welded using ARCOSITE B5 flux. Cost-wise, no other conventional method of cladding was practical. Arcos weld metal quality guarantees corrosion resistance . . . freedom from maintenance. ARCOS CORPORATION, 1500 S. 50th Street, Philadelphia 43, Pa.

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Section News and Events

as reported to Catherine O'Leary

WELDING METALLURGY

Phoenix, Ariz.—The sixth regular meeting of the season of the *Arizona* Section was held on Wednesday, February 19th in the Sky Room of the Sahara Hotel.

Guest speaker was W. A. Saylor AWS, chief metallurgist for Consolidated Western Sales, Maywood, Calif. plant. Mr. Saylor showed some interesting slides and spoke of the present and future trends in welding and metallurgy.

STAINLESS-STEEL BRAZING

Phoenix, Ariz.—The regular meeting of the *Arizona* Section was held in the Sky Room of the Sahara Hotel on Wednesday, March 19th.

Guest speaker was R. L. Peaslee AWS, vice president of Wall Colmonoy Corp. He gave a very interesting speech on "Brazing of Stainless Steel for High-Temperature Service."

ULTRASONIC TESTING

Phoenix, Ariz.—The regular meeting of the *Arizona* Section was held in the Sky Room of the Sahara Hotel on Wednesday, April 16th.

Guest speaker was Charles G. McClure of Sperry Products Co., Danbury, Conn. Mr. McClure showed a color movie and slides which described the ways of ultrasonic testing of metals. He also gave a talk on the subject.

WELDABILITY OF STEELS

Birmingham, Ala.—The final meeting of the 1957–58 season for the *Birmingham* Section was held April 8th at Gulas' Restaurant with an attendance of 67 members and guests.

Prior to the technical session, the newly elected officers for the 1958–59 season were introduced by G. P. Black, retiring chairman. These officers are: E. H. Turnock, chairman; R. A. Davis, vice chairman; and K. V. Nickell, secretary.

Dr. Bernard R. Queneau, asst. manager, Department of Metallurgy, Inspection and Research, T. C. I. Division of U. S. Steel, presented a very informative talk on the metallurgical aspects of the weldability of steels and a brief review of the conditions of stress that can cause ductile metals to fail with a brittle fracture. The effects of preheat, postheat, rate of cooling, type of welding and other

SECTION MEETING CALENDAR

JUNE 27

CAROLINA Section. Plant tour Babcock & Wilcox Co. Boiler Works, Wilmington, N. C. 4:00 P.M. 6:00 P.M. dinner, 7:00 P.M. technical session at The Ark Restaurant. "Setting Up Welding Procedures and Qualification," E. C. Korten, Hartford Steam Boiler Inspection and Insurance Co.

JUNE 28

CAROLINA Section. Deep sea fishing trip.

Editor's Note: Notices for September 1958 meetings must reach Journal office prior to July 1, so that they may be published in August Calendar. Give full information concerning time, place, topic and speaker for each meeting.

CENTRAL STATES WELDING CONFERENCE HELD IN CINCINNATI

Cincinnati Section held its Second Annual Central States Welding Conference on March 20th. Pictured above are some of the speakers and section officers who participated in program. Seated (*left to right*) are: Harold E. Schultz, District 5 director; Wm. F. Brown, section chairman; R. L. McKenney, second vice chairman; M. A. Levinstein, secretary-treasurer; C. T. Whelan, past chairman; and G. H. Lynn, executive committee. Standing, in the same order, are: Louis Michelson, dinner speaker; Cecil C. Peck, technical speaker; Nikolajs Bredzs, technical speaker; Geo. Hoppin III, executive committee; Robert L. Losee, program chairman; A. Paolino, executive committee

thermal factors in welding were discussed in their relationship to the microstructure and mechanical properties of the steel being welded. Dr. Queneau concluded his talk with a short discussion of the effect of hydrogen on cracks formed in the weld and methods of minimizing this condition.

MAGNETIC-FLUX WELDING

Greensboro, N. C.—The regular meeting of the *Carolina* Section was held in the Green Room of the Mayfair Restaurant, Greensboro, on March 25th with an attendance of 74 members and guests.

Featured speaker was K. W. Clark of the Linde Co. who talked on magnetic-flux gas-shielded welding. The talk was accompanied by slides and color motion picture.

NEW BRAZING DEVELOPMENTS

Chicago, Ill.—Seventy-eight members and guests of the *Chicago* Section met in the auditorium of the Peoples Gas Lite & Coke Co. on April 11th, to hear D. C. Herrschaft of Handy and Harman discuss the latest developments in brazing to join metal parts in the aircraft industry. Slides were used to illustrate the talk, and a lively discussion followed.

Before the meeting, a sound color film entitled, "Petrified River," was shown through the courtesy of the Modern Talking Pictures of Chicago.

ANNUAL WELDING CONFERENCE

Cincinnati, Ohio.—The *Cincinnati* Section held its Second Annual Central States Welding Conference on March 20th at the Sheraton Gibson Hotel. Approximately 75 registered for the one-day technical program and evening dinner.

Speaker of the evening session was Louis Michelson, manager Rocket Engine Section, Flight Propulsion Laboratories, AGT Division, General Electric Co. He gave an excellent talk on rocket engines and their use in the space program.

Two speakers at the morning session were Forbes Miller AWS, Research Department, Wall Colmonoy Corp., Detroit, whose subject was "Brazing Heat Resistant Metals for High-Temperature Service"; and Cecil C. Peck AWS, president of Cecil C. Peck Co., Cleveland, Ohio, whose subject was "Tooling for Mechanized Welding."

Speakers at the afternoon session were: Thomas C. Falter AWS, welding engineer, Frigidaire Division, GMC, Dayton, Ohio, whose subject was "Automatic Resistance Welding Applications"; Helmut Thielsch AWS, metallurgical engineer, Grinnell Corp., Providence, R. I., whose subject was "Why Weldments Fail"; and Nikolajs Bredzs AWS, Armour Research Institute, Chicago, Ill., whose subject was "Lithium-Bearing Brazing Alloys."

RESISTANCE WELDING

Cincinnati, Ohio.—The program for the April 22nd meeting of the *Cincinnati* Section featured two talks on resistance welding followed by an RWMA movie showing high production automated machinery as well as actual samples of the new welding techniques covered in both presentations.

The first talk was given by Arthur Schueler, chief development engineer, Precision Welder and Flexopress Corp. His talk covered the magnetic force type of welding. He showed many examples of the use of this welding where expulsion must be kept to a minimum. Of significant interest was the use of this welding to attach brackets and the like to a vinyl-coated steel without damage to the vinyl coating. The second talk was by Lawrence W. Mecklenborg of the same firm. Mr. Mecklenborg is the chief metallurgist at Precision. He discussed the use of magnetic force welding in the transistor closure technique. Conventional methods of welding resulted in the development of excessive heat which damaged the transistor and the glass seals. In addition, welding by this method permitted the joining of materials that were not readily weldable. He also discussed silver contact tape welding. Of major interest was his description of a new process called "foil seam welding" which was developed in Germany and is now licensed for use in the United States. This method consists of welding a thin metal ribbon on the top and bottom of a butt joint and effecting a completely sound weld. The advantages of the process are: (1) the use of a butt joint, (2) lower contact pressures, (3) lower clamping force, (4) higher welding speeds and (5) the elimination of oil canning.

Both presentations were very well received by the membership present.

The meeting was held in the Engineering Society Headquarters of Cincinnati.

EFFICIENT USE OF STEEL

Cleveland, Ohio.—The *Cleveland* Section's regular April meeting held on April 9th at the Hotel Manger returned to the more or less standard pattern of sponsored social hour, dinner and technical speaker. In spite of the restricting influence of the somewhat retarded productivity in

BLODGETT ADDRESSES CLEVELAND SECTION

Omer Blodgett, *(right)*, principal speaker at the April meeting of the Cleveland Section, shows Gerrit Zoethout of Holland the difference in stiffness between a rigid beam and a simply supported beam

DEAR MR. ROSSI:

On page 392 of the April issue of the JOURNAL, my picture is incorrectly identified as G. S. Hoppin III.

In deference to Mr. Hoppin, will you please inform your readers that he is much more photogenic than I?

Sincerely yours,
General Electric Co.
(*Signed*) N. J. WOODS
Welding Specialist
PED Large Fab.—Bldg. 800

local plants, a large group of very interested mean and one woman were present.

The main attraction was the speaker and his timely subject, "The Efficient Use of Steel." Omer Blodgett AWS, design consultant with Lincoln Electric Co., pointed out some interesting facts about steel and its use. Using some excellent demonstrations, chalk talking and slides, he explained the best sections for conditions of bending, twisting and torsion. Mr. Blodgett showed how steel's properties, when correctly used in designs, create surprising savings in materials.

The talk was one of the outstanding of the year and pointed up the challenge we all have to make welding a more competitive fabricating process in the market that is becoming increasingly cost-sensitive.

JOINT DESIGN

Denver, Colo.—The regular monthly meeting of the *Colorado* Section was held on April 8, 1958, at the El Rio Grande Cafe in Denver.

Members and guests gathered together at 6:00 P.M. for a social half-hour, during which they renewed acquaintances with friends in the welding industry. At 6:30, the gathering sat down to a pleasant dinner.

The speaker for the evening was L. J. Cunningham AWS, asst. supt. of pipelines, Northern Natural Gas Co., Omaha, Neb. He discussed problems and research on welding joint design. He was well qualified to do this since his experience in welding dates from 1922. It was an exceptional talk and much appreciated by the group.

AUTOMATIC RESISTANCE WELDING

Dayton, Ohio.—On Tuesday, April 8th, 35 members of the *Dayton* Section heard an outstanding talk on the subject, "Automatic Resistance Welding Applications." Speaker was Thomas C. Falter, welding engineer, Frigidaire Division, GMC, and secretary of the section. He described the major automated welding lines used at Frigidaire in the fabrication of refrigerator cabinet shells, condensers and drier filters by the resistance-welding process. The talk was illustrated with slides and a color film.

PLANT TOUR

Appleton, Wis.—Fifty members and guests of the *Fox Valley* Section made a tour of the plant of the Thilmany Pulp & Paper Co., Kaukauna, Wis., on the afternoon of Friday, April 18th. The tour was followed with dinner at Van Abels in Hollandtown.

PLANT VISIT

Houston, Tex.—On the 26th of March, 128 members and guests of the *Houston* Section, the Austin Division and the Texas City Division made a tour of the integrated steel plant of the Sheffield Division, Armco Steel Corp.

The tour proved to be a very interesting one. It required several hours to see the blooming mill, plate mill, the structural-steel mill, the wire mill and the open hearth furnace sections. The operations were explained in detail and plenty of time was devoted to watching the actual work done on the steel in its various forms.

Among those responsible for the success of the welding metallurgy course sponsored by the Kansas City Section were (*left to right*) T. H. Nicholl, class instructor; B. G. Harrington, section chairman; J. M. Payne, member, Nomenclature and Definitions Committee; and A. G. Hedstrom, chairman, Section Educational Committee

WELDING COURSE SPONSORED BY KANSAS CITY SECTION

Mr. Nicholl shown addressing one of the large groups attending the welding metallurgy course at Haag Hall on the University of Kansas City campus

KANSAS CITY SECTION HEARS GROVER ON STRUCTURAL WELDING

Part of the large crowd on hand at the March 13th meeting of the Kansas City Section. LaMotte Grover was the guest speaker

Mr. Grover, left, sharing a light moment with fellow engineers George Lamb, center, and E. S. Elcock. Mr. Grover spoke on "Structural Welding—Design Materials and Construction Practices"

Section officers pose with Mr. Grover. Left to right are: Program Chairman T. O. McDowell, Chairman B. G. Harrington, Vice Chairman D. Burrows, Mr. Grover, and Treasurer J. R. Warn

Preceding the tour, a fine barbecue supper was enjoyed at the employe picnic grounds.

The Sheffield Division was very hospitable in handling the visitors and a vote of thanks is due to them for the excellent way in which they managed the program for the evening.

PLANT TOUR

Speedway City, Ind.—Sixty-two members and guests attended the March meeting of the *Indiana* Section, held on March 28th at the Speedway plant at the Linde Co. A tour of the plant and a demonstration of light-gage inert-gas metal-arc welding took place in the afternoon.

A delicious dinner was served in the plant cafeteria followed by a Linde film on gas-shielded magnetic-flux welding, and an illustrated talk on inert-gas metal-arc welding with small diameter wire given by J. W. Carrier.

The section was honored with a visit by J. Blankenbuehler, director-at-large, who gave a short talk on the future activities of the Society.

WELDING METALLURGY

Kansas City, Mo.—A very successful 10-week course in "Welding Metallurgy," held one afternoon a week at Haag Hall on the University of Kansas City campus was sponsored by the *Kansas City* Section. There was an enrollment of 116 students comprised of 76 engineers, designers, draftsmen and inspectors; 15 superintendents, general foremen; and 14 welders. The instructor for the course was Thomas H. Nicholl AWS, district manager of the Lincoln Electric Co. Much credit for making the course possible goes to the Educational Committee composed of Chairman A. G. Hedstrom, contracting engineer, Kansas City Structural Steel, Kansas City, Kan.; Thomas H. Nicholl, Dr. R. T. Howard, James W. Weldon Laboratory, Kansas City, Mo.; and Charles B. Minnich of the James W. Weldon Laboratory.

Guest speakers were Frederick D. Seaman, Aviation Gas Turbine Division, Westinghouse Electric Co., Kansas City, Mo.; Gordon H. Moline of Metallurgical, Inc., Kansas City, Mo.; Hugh A. Springer, Union Wire Rope Corp., Kansas City, Mo.; and Dr. Howard and Charles Minnich.

PIPE WELDING

Kansas City, Mo.—The attendance of the April meeting of the *Kansas City* Section, held on April 10th, was again outstanding, the total being approximately 52 members and guests.

A pre-dinner cocktail hour began at 5:30 P.M. at the Golden Ox Restaurant and was followed by a delicious beef dinner.

After a breather of 15 minutes, the group reassembled to hear the remarks of "Shorty" Cunningham who is assistant superintendent of pipelines in the Omaha office of Northern Natural Gas Co. Mr. Cunningham illustrated his talk on research in pipeline joint design with slides.

TRAVELOGUE

Long Beach, Calif.—The *Long Beach* Section turned over their regu-

lar meeting, held on March 21st, at Eatons Chicken House to Lester Golgart (MS), of El Camino College.

Mr. Golgart was selected by Stanford University to represent them as welding education specialist in the Philippine Islands for one year.

At the completion of this year Mr. Golgart and family returned to the United States via Hong Kong, China, Thailand, Pakistan and Europe. The Long Beach members and guests made this trip with Mr. Golgart through the media of 35-mm color slides.

Not only were the colors outstanding but this was a very good lesson in geography and was enjoyed by all.

GOLGART DISCUSSES COLORFUL TRAVELS

Dressed in the formal attire of the people of the Philippine Islands, Lester Golgart shows some of souvenirs collected during an extended trip through Asia and Europe. Mr. Golgart spoke at the March meeting of the Long Beach Section

PLANT TOUR

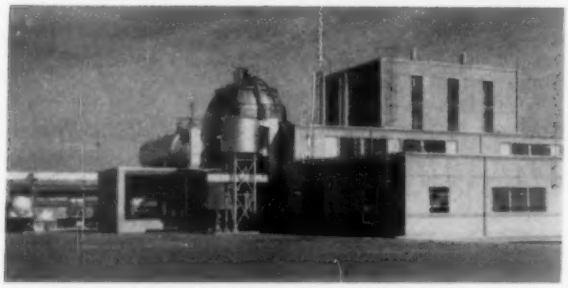
La Puente, Calif.—On April 3rd, approximately 85 members and guests of the *Los Angeles* Section *Aircraft and Rocketry Panel* had the pleasure of viewing, first hand, the manner in which many important gases used in the welding industry and medical profession are processed.

The visitors were the guests of the Air Reduction Pacific Company of Los Angeles at their new $\$7^1/_2$ million air-liquefaction plant, located in Industrial City, La Puente, Calif.

Host of the evening was Emmet W. MacCorkle, Jr., vice president of the Air Reduction Pacific Co. Arrangements were made by the company for bus transportation from the Elks Club in Huntington Park and return. A few brief talks by officials of the company were followed by a movie in color entitled, "Whatever We Do," which showed the important role these various gases play in maintaining and creating life in itself.

The tour was conducted in groups of ten by sales representatives of the Air Reduction Co., who explained the functions and purpose of each unit as

LIQUEFACTION PLANT VISITED BY ROCKETRY PANEL



New liquefaction plant of Air Reduction Pacific Co. at Industrial City, La Puente, Calif., visited by the Aircraft and Rocketry Panel , Los Angeles Section, on April 3, 1958

Part of the many members and guests of panel assembled to hear talk on liquid gases and to participate in interesting tour

Plant Superintendent A. W. Anderson explains the many processes involved in the manufacture of liquid gases

Airco Vice-President E. W. MacCorkle shows what oxygen looks like in the liquid form

Airco representative explains the workings of helium Cryostat to two members of the panel

This 70-foot towboat, and two 120-foot boats, were constructed in stainless steel from the main deck down, for service at U. S. Steel Corporation Clairton Works, Pittsburgh.

Some of the 20 Vickers Controlarc welders in service at St. Louis Shipbuilding and Steel Co.

"Sewing a seam" in stainless steel with the VICKERS® *Controlarc DC Welder*

Vickers Controlarc DC Welders played an important part in an unusual project by St. Louis Shipbuilding and Steel Company: the construction of the first inland waterway towboats with stainless steel hulls. The three boats were built for service on the Ohio and Monongahela Rivers at U. S. Steel Corporation's Clairton Works, Pittsburgh.

A big feature of the Controlarcs' performance on this job was elimination of stub loss on stainless steel electrodes by *automatic* maintenance of a constant current setting from arc strike to end of pass. With a ton and a half of costly electrodes used on the 10,500 feet of welding, dollar savings were appreciable.

Suitability of the Controlarc for Arcair gauging and cutting was another reason for the choice of this machine.

For better performance on *any* welding job, the Vickers Controlarc magnetic amplifier-rectifier DC Welder provides automatic control of *current* and *type* of arc adaptable to changes in welding conditions. For complete information on this unusual welding machine, write today for Bulletins EPD 7116-1.

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LOS ANGELES SECTION HEARS DRAHOS

Frank Drahos presenting his paper at the April 17th meeting of the Los Angeles Section

Some of the many members and guests of the section who turned out to hear Mr. Drahos' speak on "Welding for Nuclear Systems Service"

Enjoying refreshments prior to meeting are (*left to right*) Leo West, Al Thompson, Al Fenlason and John Ross

Also having a good time are Arnold Jensen, Jack Riley, Don Cooney, Chet Shira and Bill Arter

they were approached, starting with the "customers' station" which is a converter unit costing 25 to 30 thousand dollars each and supplied to the customer without cost. This was followed by the step-by-step viewing of the many types of mobile units, liquefaction units, manner of quality control and purification units. Approximately 3 hours time was consumed in a very interesting and educational evening's program which concluded with refreshments. The event was highly enjoyed and appreciated by all those in attendance.

NUCLEAR SYSTEMS

Huntington Park, Calif.—Featured as the guest speaker at the April 17th dinner meeting of the *Los Angeles* Section, was the past chairman of the section, Frank R. Drahos. Mr. Drahos is senior metallurgist for the Byron-Jackson Division, Borg Warner Corp. His subject for the evening was "Welding for Nuclear Systems Service." His subject was quite timely and of exceptional interest, especially since welding is one of the most important factors in the growth of the nuclear industry. Mr. Drahos explained why ordinary methods of welding and inspection of materials are not always acceptable for nuclear systems service. He explained how quality control of welding techniques, welding operators and designs are of vital necessity. The talk, well sup-

MAHONING VALLEY SECTION HOLDS RESISTANCE-WELDING CLASSES

Resistance-welding school members attending a lab session at the plant of the Taylor Winfield Corp. in Warren, Ohio

Another group of interested students watching lab demonstrations at Federal Machine & Welder Co. plant

DATO EXPLAINS GAS-SHIELDED MAGNETIC-FLUX WELDING

"Ed" Dato was the guest speaker at the March 18th meeting of the New Jersey Section

A large crowd was on hand to hear Mr. Dato speak on the gas-shielded magnetic-flux welding process

ported by numerous slides, covered in detail the welding, testing and inspection of reactor units.

RESISTANCE WELDING

Youngstown, Ohio.—The *Mahoning Valley* Section has successfully concluded a resistance-welding school which was held during March and April as an educational project. The course consisted of 6 weekly sessions from March 4th through April 8th and was held in the auditorium of the Ohio Edison Co. The first session consisted of a lecture and film on the basic principles of resistance welding and was presented by Emmet Craig of Federal Machine and Welder Co. The second session consisted of lab sessions and plant tours at the plants of the Federal Machine and Welder Co. and Taylor-Winfield Corp. in Warren, Ohio, both manufacturers of resistance-welding equipment.

Stuart Rockafellow AWS, of Robotron Corp. delivered an interesting talk at the third session covering electronic welder control. The fourth lecture covered shop practice and quality control and was presented by George Zeis of Harrison Radiator Corp., Buffalo, N. Y.

Foss Woodward of Taylor-Winfield Corp. presented the fifth lecture which covered some of the special mass-production machinery used in resistance welding. The sixth and last session consisted of a plant tour of the Westinghouse Transformer Division at Sharon, Pa. This plant uses resistance welding quite extensively in the fabrication of its transformer tanks.

The course created considerable interest in the Mahoning Valley area and the attendance substantially exceeded the original estimate. The attendance at each session averaged 170 or better.

The course was conducted under the chairmanship of Emmet Craig, educational committee chairman of the local chapter and chief sales engineer at the Federal Machine and Welder Co. He was assisted by Fritz Forthoefel of the Lincoln Electric Co., president of the local chapter, Bob Foxall and Peter Allen of the Federal Machine and Welder Co., Forrest Johnson of American Welding and Manufacturing Co. and Harry Kauffman of Taylor-Winfield Corp.

MAGNETIC-FLUX WELDING

Newark, N. J.—Approximately 85 members and guests of the *New Jersey* Section were on hand to hear the technical speaker for the evening J. E. Dato AWS, Linde Co., give an excellent presentation on gas-shielded magnetic-flux welding at the March 18th dinner meeting held at the Essex House Hotel in Newark.

With the help of projected slides, some in color, Mr. Dato described the equipment as somewhat similar to that used in submerged-arc welding using bare wire from 300-lb drums. Magnetic flux and CO_2 gas are automatically fed to a gun or torch where the welding current establishes a magnetic field around the wire attracting the flux to the wire. As a result, the wire or electrode is flux coated.

Excellent mechanical properties are claimed by a yield strength of 66,000 psi, a tensile strength of 78,000 psi and an elongation of 28%.

Deep penetration on horizontal fillets and X-ray quality butt welds with easy slag removal were obtained in addition to deposition rates 50% faster than those provided by manual electrodes.

PHILADELPHIA SECTION APRIL PANEL

Panelists who discussed the welding of low-chrome alloy steels on April 4 were (*left to right*): James A. Pratt, Joseph E. Carney, Charles D. Cooper and Walter H. Wooding (moderator)

A dinner attended by 59 members and guests preceded the technical meeting followed by coffee speaker Herbert Pflaster, a lawyer and accountant, whose subject was "Individual Federal Income Taxes."

The evening's activities were concluded by an after-meeting snack and get-together.

LOW-HYDROGEN ELECTRODES

New York, N. Y.—The final 1957–58 meeting of the *New York* Section was held on Tuesday, April 8, 1958. The speaker of the evening was D. C. Smith AWS, chief metallurgist, Electrode Division of the Harnischfeger Corp., Milwaukee, Wis.

Dr. Smith's announced topic was "Arc Welding and Electrodes," but inasmuch as the subject was so broad Mr. Smith limited his discussion to the welding of armor and high-tensile steels, with conventional, low-hydrogen and low-hydrogen iron-oxide electrodes. Dr. Smith favored the latter two types and presented a convincing tabulation of their advantages and also discussed the limitations or shortcomings of all types.

An inspired question-and-answer period followed Dr. Smith's talk. The technical chairman for the evening was J. L. Cahill of the New York Navy Yard.

The meeting was held at Victor's Restaurant—1 East 35th Street, New York City, and an excellent dinner was served prior to the meeting.

HIGH-TEMPERATURE BRAZING

Pittsfield, Mass.—The final technical meeting of the 1957–58 season for the *Northern New York* Section took place on April 10th, at the Stanley Club in Pittsfield. The speaker was George S. Hoppin III AWS, of the Metals Joining Section, Flight Propulsion Laboratory Department, General Electric Co. His talk was "High Temperature Brazing."

American Welding Society
Philadelphia Section

Your thoughtful gift of flowers in memory of Dr. Comfort A. Adams was greatly appreciated.

Such kindly thoughts bring real comfort at the time of loss and in the many days that follow.

Sincerely,
Ethel M. Adams

RESISTANCE-WELDER DESIGN COVERED BY BODENHEIM

Francis A. Bodenheim speaking on "Trends in Automatic Resistance-Welder Design" at the April 21st meeting of Philadelphia Section

Here, guest speaker Bodenheim is shown at dinner with Program Chairman Carl Schaub (*left*) and Jim MacKinney

RESISTANCE-WELDING AUTOMATION

Philadelphia, Pa.—The *Philadelphia* Section held its regular monthly technical meeting on Monday, April 21st, at the Engineers' Club. The subject on resistance welding served to attract many who do not attend sessions on other processes. Approximately seventy members and guests heard a talk by F. A. Bodenheim AWS, sales manager of the Federal Machine and Welder Co. He was ably assisted by C. W. Middlestead AWS, during the question-and-answer period. Mr. Middlestead operates his own company in Philadelphia.

Mr. Bodenheim spoke on the topic, "Trends in Automatic Resistance-Welder Design." He mentioned that resistance welder development had been spurred on by the Second World War, but had really "gone into high gear" since that time. There had been some over-development and over-complication which had proved to be detrimental, temporarily, to the over-all program. His talk favored the industrial engineering aspects of resistance welder development and its relation to automation in the operation of a plant.

In his talk, Mr. Bodenheim discussed automatic resistance welders in three main categories. The first of these was the machine which performed multiple resistance welds but no other operations. Next in order was the multiple operation machine which also incorporated processes other than welding. The final step was for complete automation of the line with the resistance welder being an important station in the line. He presented case histories of each category giving costs, rates of production and manpower requirements before and after the application of automatic welding. The production rates which were obtained with multiple operation machines or automated lines were

1958 DIRECTORS OF SAN ANTONIO SECTION

Seated (*left to right*) are: Ray Johnson, E. E. Wagner, Fred W. Smith, Bob Hamilton and J. A. Rounds. Standing, in same order, are: Robert Gordon, Franz Engels, H. F. Burkhart, C. E. Hosier and Roy D. Sprague

HEAR HAMMER ON METALLURGY OF WELDING

Large group attended the April 22nd meeting of San Antonio Section to hear W. A. Hammer speak on the "Metallurgical Why's of Welding"

most impressive at 600 to 700 assemblies per hr.

The talk was very well illustrated by means of slides and a motion picture.

The April Panel Discussion meeting was held on April 4th at the Engineers' Club. Walter H. Wooding, chairman of the panel discussion committee, acted as moderator on the subject of "Welding of Low Chrome Alloy Steels." He was assisted by Joseph E. Carney, Sun Oil Co.; Charles D. Cooper, Metal and Thermit Corp.; and James A. Pratt of Westinghouse.

WELDING DISTORTION

Providence, R. I.—The newly formed *Providence* Section held its fifth meeting of the season on January 15th at Johnson's Hummocks in Providence, with nearly 100 members in attendance.

Guest speaker was LaMotte Grover AWS, welding engineer with Air Reduction Co., New York. Mr. Grover presented a fundamental discussion on the factors covering distortion, and made recommendations on the control and correction of undesirable distortion. He explained various practical methods followed to control distortion by fixturing, welding sequence, joint preparation, pre- and postheating, filler metal selection, etc.

Mr. Grover's talk, accompanied by numerous slides, illustrated many of the different types of distortion encountered and the solutions employed to insure sound weldments with an absence of or a minimum of harmless distortion.

Prior to the dinner, members and guests gathered as usual for their social hour. After dinner, the section chairman, Mr. Thielsch, made a few brief comments on his recent visit to Europe which were very interesting and enjoyed by all.

Carl Rimmler, chairman of the welding problems committee, also gave answers to several welding problems submitted by members. Mr. Rimmler's very illustrative and humorous approach held the attention of the audience and helped to provide local industry with the technical answers desired. By means of the welding problems committee, local industry can obtain solutions to vexing welding problems and insure better products at lower cost.

METALLURGY

San Antonio, Tex.—The *San Antonio* Section held its regular dinner meeting on Tuesday, April 22nd, at Stranger's Party House. W. A. Hammer, metallurgical engineer for Jorgensen Steel Company of Dallas, gave a very fine talk on "Metallurgical Why's of Welding" that proved beneficial to all.

SECOND WELDING SHOW

San Jose, Calif.—The Second Welding, Brazing and Heat-treating Show sponsored by the *Santa Clara Valley* Section was very well received by both exhibitors and visitors. The exhibitors spoke highly of the type of visitors who attended the show on March 27th, 28th and 29th. There was a total of 22 separate booths with 45 companies represented. The booths covered a total of 4080 sq ft. The show was held at the Exposition Hall of the Santa Clara County Fair Grounds in San Jose. The exhibitors also expressed their appreciation of the conduct and organization of the welding show.

HISTORY OF WELDING

San Jose, Calif.—Ray L. Townsend AWS, president of Tweco Products Inc., Wichita, Kan., presented a history of welding at the April 29th meeting of the *Santa Clara Valley* Section. Preceding the pictorial projection Mr. Townsend told about the early processes and material that have led to today's vast knowledge of fusion welding. In his talk he referred to information published in the early days of welding. The meeting brought out that few people, by comparison, who are today engaged in welding pursuits were in the welding field prior to 1940.

WELDING CODES

Toledo, Ohio.—William Kramer of the Chicago office of the Pure Oil Co. spoke on "Codes for Welding" at the April dinner meeting of the *Toledo* Section held at the Maumee River Yacht Club on April 8th.

Mr. Kramer reviewed the need for safety codes in boiler work. The speaker then chronologically itemized the inclusions in the codes which affected or pertained to welding. Important milestones were mentioned. In 1925 welding was first acknowledged in an unfired pressure-vessel code. In 1931 the first all-welded pressure vessel was manufactured under the ASME code.

The speaker revealed the current trend is now for individual states to adopt the ASME code as the state code.

SILVER-ALLOY BRAZING

Thompsonville, Conn.—The regular meeting of the *Western Massachusetts* Section was held at the Silhouette Restaurant, Thompsonville,

WELDING SHOW SPONSORED BY SANTA CLARA VALLEY SECTION

In the center, top photograph, Charley Robinson (*extreme left*) and Ray Townsend (*extreme right*) relax with other "men of welding" during the Second Welding, Brazing & Heat Treating Show held on the Santa Clara County Fair Grounds in San Jose, Calif. Sponsored by the Santa Clara Valley Section, the show featured the exhibits of 45 companies and was held from the 25th through the 27th of March

Conn., on Tuesday evening, April 8th.

Technical speaker was A. W. Swift AWS, Engineering Division of Handy & Harman, who spoke on "Silver-Alloy Brazing." His talk was illustrated with slides. A lively discussion followed.

ANNUAL SPRING SYMPOSIUM

Grand Rapids, Mich.—The Annual Spring Symposium of the *Western Michigan* Section was held on Friday, April 11th, at the Morton House in Grand Rapids. This was an all day affair starting with registration at 8 A.M. Speakers on various subjects which have been of the most interest throughout the year were featured.

The first session was addressed by Howard Adkins AWS, of the Kaiser Aluminum and Chemical Co. on the practical aspects of inert-gas-shielded arc welding of aluminum by both the tungsten-arc and consumable-electrode methods. Mr. Adkins' lecture, accompanied by slides and film, was very ably presented and was one of the highlights of the meeting.

After the session there was a coffee break followed by the second speaker, Stuart Rockafellow AWS, of the Robotron Corp. of Detroit. Mr. Rockafellow spoke on resistance-welding controls which was of vital interest to all, as resistance welding is one phase of welding that is commonly used in this area. Luncheon was served in the same room where the meetings were held.

The afternoon sessions were led off by A. J. Dearing AWS, of the A. O. Smith Corp., Milwaukee. Mr. Dearing spoke on fixturing for automatic welding, a subject he is well qualified to discuss due to his great amount of practical experience in this field. The afternoon coffee break followed.

The last session of the day was covered by C. R. Gingerich of the Linde Co., Detroit. Mr. Gingerich spoke on oxyacetylene brazing and showed an excellent film on the subject.

It was agreed that the caliber of speakers was the best and the affair was a great success.

PLANT TOUR

East Stroudsburg, Pa.—Fifty-four members and guests of the *Lehigh Valley* Section traveled to East Stroudsburg on the evening of April 7th, where they toured the plant of the Patterson-Kelley Co.

As engineers and manufacturers of heat-transfer equipment and pressure vessels, the Patterson-Kelley Co. welds stainless steel, copper and common carbon steels. The members noted with interest the many types of shielded-arc-welding processes and welding setups that the company employs in its plant. The visitors also spent quite a bit of time inspecting the X-raying and testing methods used by the company to meet the various code requirements.

Dinner at Walps Restaurant in Allentown preceded the tour.

INERT-GAS WELDING

Louisville, Ky.—One of the largest turnouts of the year of the *Louisville* Section, over 40 members and guests, were present on April 22nd to hear H. D. Mann AWS, of Air Reduction present a semi-technical talk entitled, "New Developments in Inert-Gas Welding." Mr. Mann had previously addressed the section and his talk had been extremely well received.

Plagued by poor attendance all year, the section officers decided to take positive steps to assure a good attendance at this meeting. Each officer contacted 8 members and invited them to the meeting. To stimulate interest further, a pre-meeting social hour was held so that the members would have an opportunity to get together socially. Coffee speaker Louis Panke of the Southern Bell Telephone and Telegraph Co. discussed future telephone equipment. A door prize was also given.

All this, together with Mr. Mann's excellent talk, produced one of the most successful meetings of the year.

WELDED BRIDGES

Baltimore, Md.—On the evening of April 18th, the regular meeting of the *Maryland* Section was held at the Baltimore Engineers Club. An unusually fine turnout of 70 members and guests was on hand for the dinner and to hear the coffee speaker, Henry Barnes, traffic and transit engineer for the City of Baltimore. Mr. Barnes described the new electronic control center for the city traffic light system. The timing is automatically changed in accordance with traffic density and direction. He also discussed other traffic problems and local solutions.

Later, approximately 85 people were present for the technical talk given by Omer Blodgett AWS, of the Lincoln Electric Co. His talk was entitled, "Welded Bridges—A Progress Report." The audience, with a number of structural and architectural design engineers present, listened to a very instructive and interesting presentation of bridge girder design. The speaker pointed out that proper calculation of girder section and web stiffeners can result in significant savings in material. Location of butt welds and weld procedure were discussed. Design in the new European bridges was shown in several slides and described primarily as box and plate girder design and pier supported. In general, they are using low-alloy high-tensile steels as the girder materials.

The lengthy and lively discussion period that followed the talk indicated the interest in the subject and the ability of the speaker.

STUD WELDING

Miami, Fla.—The *South Florida* Section held its regular monthly meeting on Wednesday evening, April 16th, at the Miami Firemen's Benevolent Association Hall. Robert D. McCahan AWS, of the Nelson Stud Welding Division of Gregory Industries, gave an illustrated talk on stud welding. Starting with a brief history of the origin and initial application of stud welding, he traced the rapid progress and expanding fields where stud welding has reduced cost and, at the same time, provided a better end product.

To complete the evening, Mr. McCahan provided a portable unit and invited the thirty-two guests and members to "shoot" studs—an opportunity enjoyed by all.

TUBE-TO-SHEET WELDING

Syracuse, N. Y.—The April 9th meeting of the *Syracuse* Section was held at the Onondaga Hotel. The dinner was attended by 25 members and guests who also heard a humorous talk by the coffee speaker, R. L. Jones, Jr., on "Scorpions and Earth Worms."

Twenty additional members were present at the technical meeting which followed to hear a member of the section, Lowell Hawthorne, head of the Welding Section Research Laboratory, Revere Copper and Brass Co., Rome, New York, speak on "Automatic Tube-to-Sheet Welding," a new process for joining tubes to flat sheet metal using a gas-shielded tungsten electrode with electronic controls. This process was developed in the Revere Laboratory with Mr. Hawthorne playing a major part. It is applicable to most common metals, and experiments in special applica-

WESTERN MICHIGAN SECTION SPONSORS SPRING SYMPOSIUM

Howard Adkins spoke on the practical aspects of inert-gas welding of aluminum at the April 11 Symposium

Resistance-welding controls were discussed before Western Michigan Section by Stuart Rockafellow

The subject of A. J. Dearing's talk was "Fixturing for Automatic Welding"

C. R. Gingerich explained the various aspects of oxyacetylene brazing

tions also are being continued.

Mr. Hawthorne's talk was well received, as shown by the number of questions he was called upon to answer.

The meeting was concluded with the awarding of a door prize after which a luncheon was served.

MODERN WELDMENTS

Worcester, Mass.—In spite of the fact that the evening of April 7th was very stormy, 42 members of the *Worcester* Section were present for dinner and 10 more attended the meeting which followed. This turnout on such an evening was a wonderful tribute to the reputation of the speaker, Thomas B. Walsh, plant manager, Avery-Saul Company, Cambridge, Mass. His talk was on "Modern Weldments." He showed a reel of film related to, and connected with, operations at the company's two plants. Then, through the medium of a "reflectoscope," he showed pictures taken by a commercial photographer of many weldments Avery-Saul have made for atomic energy equipment, as well as bases, etc., for the machine tool manufacturers in the New England region. These features, together with his commentary on each picture shown, and the customary question period, kept the meeting in session until 10:15 P.M.

These pictures and the commentary covered all phases of weldment fabrication and assembly, namely, burning, beveling, shearing, punching, drilling, fitup, welding sequence and welding processes from manual arc to fully automatic, and even included a few home-made "Rube Goldberg" devices that work very well in their shops. They included X-ray, heat treatment of outsize weldments, sand blast, paint and finally shipment to the customer. This latter posed one or two interesting problems, where the weldment involved was much too large to go through any door. This necessitated removal of a portion of the building wall, and then by manipulation just managed to slide by the columns of the building itself. His company recognizes no limit to the length, width or height, of a customer's weldment requirement. They have a staff of qualified help and are continually working to Army and Navy specifications.

Mr. Walsh had addressed this section 5 years ago, at which time he also presented an interesting talk. Avery-Saul's experience during the intervening period made this much more informative. Who would be rash enough to hazard a guess as to what progress the next five years will unfold?

AN INVITATION TO AUTHORS

—to participate in the American Welding Society's

40th ANNUAL CONVENTION AND MEETING
Chicago, Ill.—Apr. 6–10, 1959

Gentlemen:

The American Welding Society will hold its 40th Annual Convention and Meeting in Chicago, Ill., on Apr. 6–10, 1959.

Each year our Society offers opportunities to Authors for bringing their outstanding work, development and research to the attention of our Membership and the welding and metals industry, by having previously unpresented and unpublished papers presented at its national meetings.

The Society's Technical Papers Committee will be happy to receive your application for entry in the 40th Annual Meeting activity. All applications, abstracts and manuscripts will be screened by the Committee, and Authors will be notified sometime in October 1958 regarding acceptance.

Each abstract should be sufficiently descriptive to give the Committee a clear idea of the content of the proposed paper. In any case, it should contain not less than 500—but not more than 1000—words. Also, in order to place the Committee in the best possible position to evaluate these papers, it is suggested that each abstract be accompanied by a complete manuscript.

The Committee reserves the right to consider all applications on the basis of acceptance for placing on the 40th Annual Meeting Program; or consideration for placing on the Program of the succeeding national meeting of the Society, the 1959 National Fall Meeting. Papers may be considered for publication in The Welding Journal regardless of acceptance for presentation at either Meeting.

Papers dealing with latest developments in (1) fabrication and maintenance of equipment used for radioactive applications, (2) pressure vessels and storage tanks, (3) equipment and pipe lines used in petroleum industry, (4) machinery design and fabrication, (5) structures, (6) automation as applied to resistance welding, inert-arc welding and other welding processes, (7) welding of castings and composite structures, (8) welding of dissimilar metals, (9) welding of aluminum, magnesium, zirconium, titanium, molybdenum and like metals, (10) brazing, (11) soft soldering, (12) welding of plastics, and (13) practical applications or "how-to-do" topics are deemed to be of particular interest at the Chicago meeting. However, any papers dealing with the educational and informative categories of welding production, engineering, research and metallurgy, are welcomed as long as the subject falls within the field of our Society's activities.

Authors' Application Forms were mailed a few weeks ago to all members of our Society; additional copies may be obtained by writing directly to AWS headquarters. To assure consideration for the 40th Annual Meeting Program, abstracts must reach AWS not later than Aug. 15, 1958.

Sincerely,
Fred L. Plummer
National Secretary

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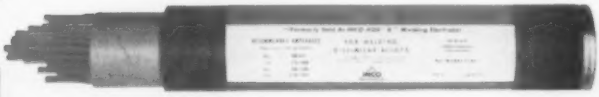

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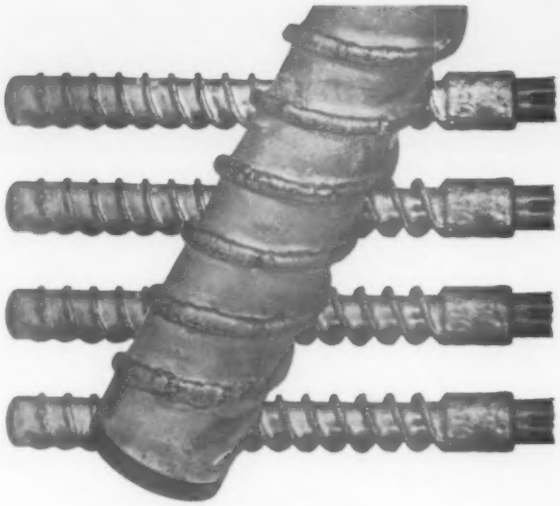

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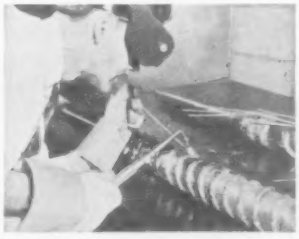

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For copies of articles, write directly to publications in which they appear. A list of addresses is available on request.

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ABSTRACTS OF CURRENT PATENTS

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.

2,807,705—Combination Electric Wire Stripper and Welder—William E. Arrain, San Diego, Calif.

In this patent, a combination electric wire stripper and welder apparatus is provided. The apparatus includes a pair of block assemblies, each having a pair of insulated side blocks and an insulated spacer fixed therebetween. The spacer has generally circular, shallow sockets on opposite sides thereof and electrode disks are held in the sockets by the blocks. Other means position the block assemblies to move them together with the electrodes in opposed but paired registration. The electrodes each have a plurality of progressively sized notches therein and are rotatively adjustable to bring corresponding notches into registration to receive and hold pieces of electrical shielded wire.

2,807,707—Apparatus for Percussively Welding Contacts Onto an Article—Robert O. Pirchler, Cicero, and Amos L. Quinlan, La Grange Park, Ill., assignors to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

A movable welding electrode is provided for carrying elements and percussively welding them onto an article in this patent. Means are provided to hold the article and other means are provided for yieldably supporting the holding means for vertical movement on indexible means provided in the apparatus. A member is present to actuate the indexible means step by step to bring different portions of the article successively into alignment with the welding electrode to weld elements onto the article.

2,807,708—Arc-Welding Apparatus and Method—Nelson E. Anderson, Berkeley Heights, William J. Greene, Scotch Plains, and Rawlins E. Purkhiser, Springfield, N. J., assignors to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

This patented arc-welding apparatus includes a welding head and means to supply a consumable electrode to the head at constant speed. A welding machine is provided and it has a drooping volt-ampere characteristic and includes a transformer with a saturable control core completely independent of the primary winding and linked in direct inductive relationship with the secondary winding. Certain means couple the output of the welding machine to the electrode and to a workpiece while other means are provided to alter the saturation of the core inversely with changes in arc voltage between the electrode and workpiece to maintain the arc voltage substantially constant between predetermined values of welding current.

2,808,493—Welding of Tubes and the Like—Joseph B. Brennan, Cleveland, Ohio.

Brennan's patent is on a method of continuously welding together a pair of bondable metal faces and it comprises pressure contacting successive longitudinal sections of the faces to be welded together and moving such pressure contacted faces only past substantially the highest intensity portion of an induction heating field to heat superficially successive longitudinal sections only of the thus contacting faces to welding temperature. While the metal faces are so moved to pass the heating field, the adjacent surfaces are ironed to eliminate formation of a flash bead.

2,808,498—Welding Torch Wire Feed—James A. Hudson, Chicago Ill., and Stanley H. Royer, Elizabeth, N. J., assignors to Union Carbide Corp., a corporation of New York.

The present patent is on an electric arc gun including a contactor for supplying electric current to a moving electrode wire while an electric motor is provided to drive feed means in the apparatus and engaging the wire to feed it to the contactor. A hollow armature is present and is rotatably journalled in the apparatus to have the wire pass through it on its way to the contactor.

2,808,499—Apparatus for Electric Arc Welding—Nelson E. Anderson, Berkeley Heights, N. J., assignor to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

Anderson's patented apparatus includes an electric wire feed roll making driving engagement with an electrode wire, an electric motor means having sufficient inertia to prevent substantially instantaneous stopping of the motor means after de-energization for driving the wire feed roll. A clutch couples the motor means to the feed roll and other means are provided to disengage the clutch substantially simultaneously with the interruption of power to the motor to effect substantially instantaneous stopping of the wire feed when the motor is de-energized.

2,808,639—Process of Securing Welding Cables to Terminals—Frederick S. Wreford, deceased, late of Detroit, Mich., by Annie A. M. Wreford, executrix, Detroit, Mich., assignor by mesne assignments, to Gar Wood Industries, Inc., Wayne, Mich., a corporation of Michigan.

Wreford's patented process is directed to the provision of welding cables wherein substantially flat-sided insulation strips cooperate with other portions of the welding cable to provide cooling liquid passage ways therein.

2,809,269—Machine for Welding Metal O-Rings—Fred H. Storck, Dayton, and William Carson Nuckles, Springfield, Ohio, assignors to United Aircraft Products, Inc., Dayton, Ohio, a corporation of Ohio.

The patented machine includes dies with arcuate grooves therein for receiving the split metal O-ring therein. Jaws are provided to grip the ring when on the dies and apply pressure thereto. Other means are provided to apply heat to the split portion for welding action.

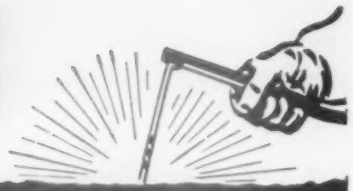
2,809,270—Machine for Welding Reinforcements for Concrete Pipes and the Like—Kenneth E. James and Alfred Dahlstrum, Baldwin Park, Calif., assignors to United Concrete Pipe Corp., Baldwin Park, Calif., a corporation of California.

This patent is on a machine for welding longitudinal and circumferential wires together where the longitudinal wires are on the outside of the circumferential wires. A first welding electrode is provided to traverse crossings between longitudinal wires and circumferential wires successively in a direction parallel to the longitudinal wires, and a second electrode is arranged to traverse-circumferential wires in trailing relationship to the first electrode and in a direction parallel to the longitudinal wires. Thus the path of current flow of at least part of the wire structure will be through a crossing previously traversed by the first electrode to anneal the weld formed at such wire crossing.

2,809,274—Percussion Welding Apparatus—Amos L. Quinlan, La Grange Park, Ill., assignor to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

In this percussion welding apparatus, an electrode supports an element and is moved towards a part-supporting means for percussive engagement between the element and the part and for welding the element and the part together. An inertia member is mounted on the electrode to move therewith and has limited movement in the same direction relative to the electrode after the electrode has been stopped for preventing rebound of the electrode relative to the part-supporting means until the weld between the part and the element solidifies.

Weldynamics



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NEWS of The Industry

M & T Marks 50th Year

Metal & Thermit Corp. this year is celebrating its fiftieth anniversary.

In 1908 a small company called the Goldschmidt Detinning Co. was established in Carteret, N. J., to utilize a European process for reclaiming tin and steel scrap from the tin plate scrap produced in the making of tin cans. This operation was the forerunner of the present Metal & Thermit Corp.

Metal & Thermit has been associated with welding from the year 1904 when the Goldschmidt Thermit Co. introduced the thermit-welding process to this country. The sale of thermit-welding equipment was supplemented in 1931 by M & T's entrance into the electric welding field. At present the concern is actively engaged in electrode, machine and accessory supplies.

Metal & Thermit is also active in other industries, such as industrial chemicals, detinning, electroplating, metals, mining and coatings. The organization's expansion is reflected in the recent completion of a $3,500,000

chemical plant in Carrollton, Ky. Executive offices are maintained in New York City, while the general offices are located in Rahway, N. J. The company also operates 11 sales offices, 6 plants and 2 research laboratories throughout the United States. There are 6 subsidiary and affiliated companies—one of which is located in Canada.

Officers of M & T are H. E. Martin, president, E. E. Anderson, C. K. Banks, C. J. Beasley, H. D. McLeese and B. W. Weber, vice-presidents, E. L. Kries, treasurer, and C. R. Hervey, controller. •

Helmet Design Award

Garland (Jim) Thompson, designer of Hobart Bros.' new line of plastic welding helmets, was given a citation and $50 check which were awarded to Hobart Bros. Co. by *Materials in Design Engineering* Magazine for the best use of material in the design of a new glass

Resistance-Welding Contest

Authors' application forms for the RWMA Prize Paper Contest, sponsored by the Resistance Welder Manufacturer's Assn., 1900 Arch St., Philadelphia 3, Pa., are still available. The deadline for mailing application forms is July 1, 1958.

The contest itself will close on Sept. 15, 1958. Prizes will be awarded to the three best papers submitted in each of the two categories, special projection and general resistance-welding classifications. The amounts of the awards will be $600, $300 and $100 for first, second and third prizes, respectively.

For your free copy of the rules and forms pertaining to this contest, write to the above organization as soon as possible.

Airco Quarterly Report

Sales and earnings during the first quarter of 1958 declined from the levels established in the first quarter of 1957, John A. Hill, president of Air Reduction Co., Inc., told the annual meeting of stockholders recently.

First quarter 1958 sales were $43,254,129, compared with sales of $46,243,507 during the first quarter of 1957, a decline of 6.5%. Net income during the first quarter of 1958 was $3,370,716, compared with first quarter 1957 net income of $4,333,945, a decline of 22%.

ASTM Meets in Boston

The 61st Annual Meeting of the American Society for Testing Materials will be held in Boston from June 22 to 27. The meetings will take place at the Statler and Sheraton-Plaza Hotels.

Argon Purity Guarantee

A firm guarantee of 99.995% purity for its argon gas has just been announced by Linde Co., Division of Union Carbide Corp., 420 Lexington Ave., New York 17, N. Y. The new higher purity gas, containing less than 50 parts per million of impurities, is Linde's regular industrial argon—available for all orders without any special price or grade category.

Linde stressed that the high-purity guarantee refers to the delivery state of the argon, not merely to the manufactured purity, and that the guarantee also holds true for all methods of delivery.

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

1959 Spring Meeting and Welding Show:
April 6–10, Sherman Hotel, Chicago, Ill.

IWDA

June 19 and 20, 1958. Annual Meeting, Howard House, Garden Grove, Calif.

Midwest Welding Conference

Jan. 28–29, 1959. Illinois Institute of Technology, Chicago. Sponsored by Armour Research Foundation and AWS Chicago Section.

fiber reinforced plastic welding helmet. Mr. Thompson received the award at an awards' dinner at the Drake Hotel in Chicago on April 17th.

Precision Appoints Representatives

Precision Welder & Flexopress Corp., Cincinnati, Ohio, recently announced the appointment of three new representatives. In Chicago, Heck & Co Inc., 5717 North Elston Ave., will handle the complete line of Precision resistance welders. In Chicago and Wisconsin, Zimmerman and Gammond, Inc., Pickwick Bldg., 3 S. Prospect, Park Ridge, Ill., will represent the Precision Flexopress line of high-speed stamping presses. In the Philadelphia area, Howard Gordon, 429 Chetwynd, Lancaster Pike, Rosemont, Pa., will handle both the welder and press lines for Precision.

Burdett Announces Appointments

W. H. Loveman AWS, president of the Burdett Oxygen Company of Cleveland, Ohio, announced the appointment of the following personnel, effective March 1, 1958.

William Kaiser AWS, former manager of the Burdett warehouse in Mansfield, has become the new general manager of the Dayton, Ohio, plant.

William Kaiser

Jack Harris, a member of the Sales Division in Cleveland becomes the new manager of the Mansfield warehouse, while Robert Kimmerle, of the Cleveland Sales Department, replaces Jack Harris in Elyria, Lorain and the northeastern section of Cleveland.

Vickers Names Clayton

Gordon H. Clayton has been appointed general manager, Electric Products Division, Vickers Inc.

Gordon H. Clayton

Before joining Vickers, Mr. Clayton spent 12 years with Power Equipment Co., most recently as head of the Special Products Engineering Development Division. He was in charge of the Engineering and Sales Division of this Detroit operation for five years. He is a graduate in electrical engineering from Wayne State University.

Grand Opening

Forty-seven of the nation's leading producers of metals, metal accessories and welding equipment and supplies took part in a welding clinic and metals

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163	425	1200
175	438	1250
188	450	1300
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213	475	1400
225	488	1450
238	500	1500
250	525	1550
263	550	1600
275	600	1650
288	650	1700
300	700	1750
313	750	1800
325	800	1850
338	850	1900
350	900	1950
363	950	2000

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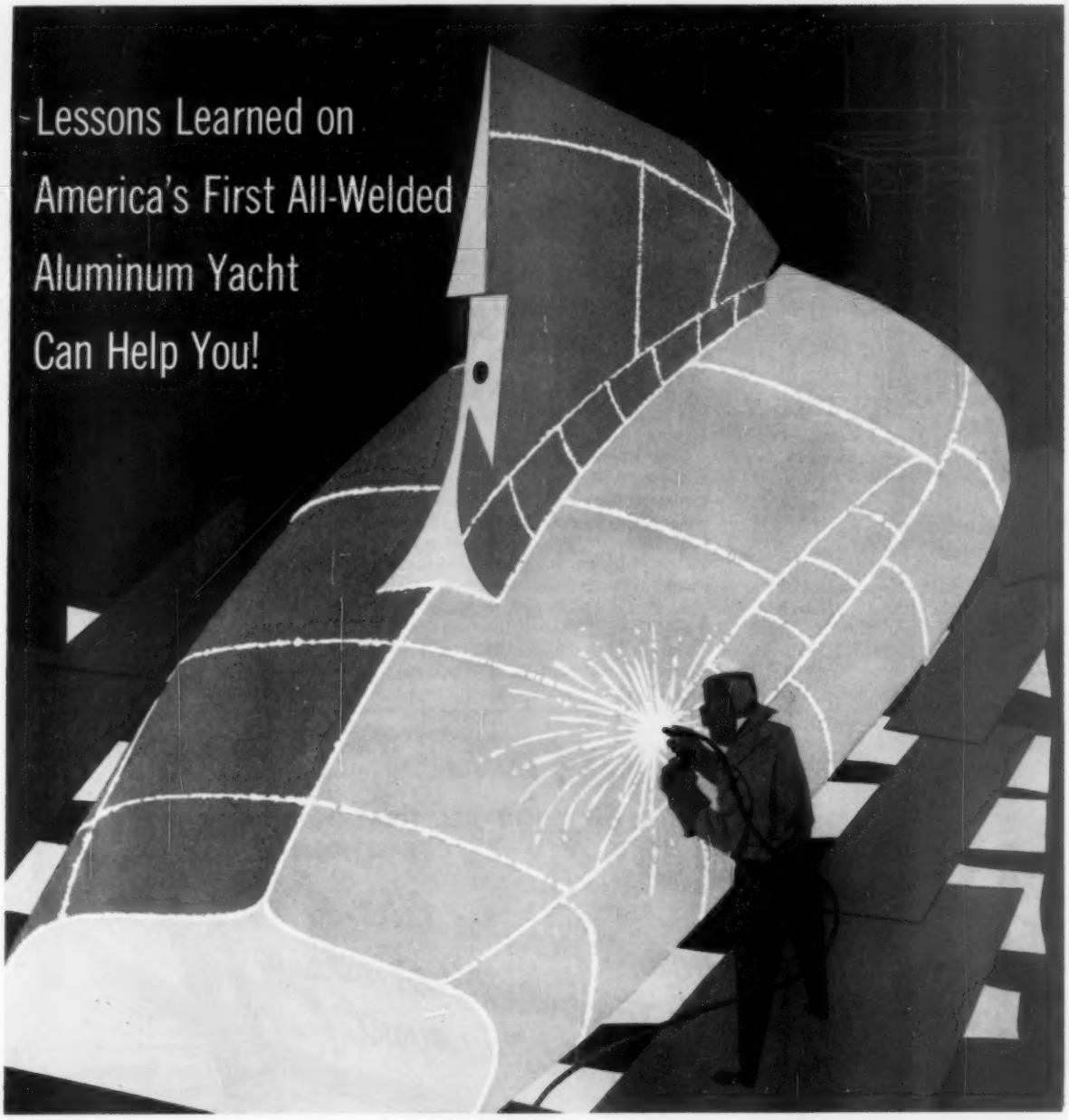
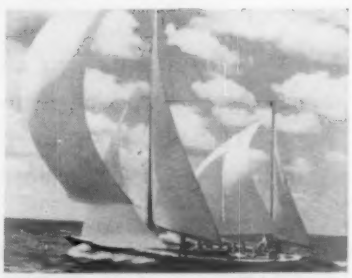


The hull of *Dyna*, America's first all-welded aluminum yacht, will be exposed throughout its life to great stresses, a corrosive environment, and constant battering and vibration. To meet this challenge, Burger Boat Company, of Manitowac, Wisconsin, turned to Alcoa Alloy 5154 and the inert-gas consumable electrode welding process.

Welders at Burger Boat Company had formerly worked exclusively with steel prior to building *Dyna*, yet they had little difficulty in adapting their skills to aluminum. They found that aluminum could be welded at a faster rate than steel, and with relative freedom from warping and distortion. Further, the light weight of the aluminum sections eased handling problems and speeded assembly.

This is another example of the many exciting possibilities in welding, brazing and soldering Alcoa® Aluminum and its alloys. Get in touch with your nearest Alcoa sales office for the kind of design and welding assistance that Alcoa was able to offer Burger Boat Company. For welding materials, contact your local Alcoa distributor listed at the right. For booklets and films that show how easy it is to weld, braze and solder aluminum, write Aluminum Company of America, 1741-F Alcoa Building, Pittsburgh 19, Pennsylvania.



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COLORADO
Denver
Metal Goods Corp.

CONNECTICUT
Milford
Edgcomb Steel of New England, Inc.
Windsor
Whitehead Metal Products Co., Inc.

FLORIDA
Jacksonville
The J. M. Tull Metal & Supply Co., Inc.
Miami
The J. M. Tull Metal & Supply Co., Inc.
Tampa
The J. M. Tull Metal & Supply Co., Inc.

GEORGIA
Atlanta
The J. M. Tull Metal & Supply Co., Inc.
Southern Oxygen Co.

ILLINOIS
Chicago
Machinery & Welder Corp.
Steel Sales Corp.
Moline
Machinery & Welder Corp.

KENTUCKY
Louisville
Williams and Co., Inc.

LOUISIANA
New Orleans
Metal Goods Corp.

MARYLAND
Baltimore
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NEW YORK
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NORTH CAROLINA
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Charlotte
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Greensboro
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OHIO
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Cleveland
Nottingham Steel & Aluminum Co.
Williams and Co., Inc.
Columbus
Williams and Co., Inc.
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Williams and Co., Inc.

OKLAHOMA
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Metal Goods Corp.

OREGON
Portland
Pacific Metal Co.
J. E. Haseltine & Co.

PENNSYLVANIA
Philadelphia
Edgcomb Steel Co.
Southern Oxygen Co.
Whitehead Metal Products Co., Inc.
Pittsburgh
Williams and Co., Inc.
York
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TENNESSEE
Kingsport
Southern Oxygen Co.
Knoxville
Southern Oxygen Co.

TEXAS
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Big Three Welding Equip. Co.
Corpus Christi
Big Three Welding Equip. Co.
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Metal Goods Corp.
Texas Welding Supply Co.
Houston
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Big Three Welding Equip. Co.
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UTAH
Salt Lake City
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VIRGINIA
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Richmond
Southern Oxygen Co.
Roanoke
Southern Oxygen Co.

WASHINGTON
Seattle
Pacific Metal Co.
J. E. Haseltine & Co.
Spokane
J. E. Haseltine & Co.

WEST VIRGINIA
Bluefield
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WISCONSIN
Milwaukee
Machinery & Welder Corp.
Steel Sales Corp.

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show in Birmingham on May 13–15, when the J. M. Tull Metal and Supply Co., Inc., opened its new Birmingham warehouse.

Many exhibits of materials and developments in the metals field were featured during the three-day show. The welding clinic, held in conjunction with it, consisted of demonstrations of the latest techniques, welding processes and equipment, including demonstrations with nickel welding wires.

Located at 1301 25th Avenue North, the 50,000 sq ft warehouse has been designed to accommodate a complete line of metals and accessories and to facilitate prompt and efficient handling of orders. Harry Homer, who has represented the J. M. Tull Co. for many years in the Alabama territory, will be manager of the warehouse.

Mallory-Sharon Expands

Mallory-Sharon Metals Corp., Niles, Ohio, world's largest integrated producer of reactive metals, has acquired the common stock of Johnston & Funk Titanium Corp., Wooster, Ohio. Through the combined facilities, Mallory-Sharon and Johnston & Funk will be better able to service requirements for wire products.

Edward R. Funk, president of Johnston & Funk, was formerly on the faculty of Massachusetts Institute of Technology and holds a doctorate degree from that university.

Adopt New Name

According to an official announcement, Shober Sales, Inc., 900 W. Weber Ave., Stockton, Calif., have changed their name to Shober, Inc. for convenience and to make their name reflect the fact that their business is primarily manufacturing and wholesaling.

Meco Names Officers

Modern Engineering Co., St. Louis, Mo., has announced its new executive assignments as follows: I. F. Fausek, chairman of the board; I. F. Fausek, Jr. AWS, president; Willis L. Reedy, vice president, production; Al V. Fausek, AWS, vice-president, sales; James F. Fausek, vice-president, industrial sales; and Robert E. Bird, secretary.

Abrasive Show

Fifty-three manufacturers of coated abrasive machine tools will demonstrate their new products in the Third National Coated Abrasives Machinery Show June 10–13 at Troy, N. Y. This year's show will take place in the new $1,000,000 product engineering building of Behr-Manning Co., a division of Norton Co., which sponsors the event.

ATTEND
AWS 40th ANNUAL MEETING
April 6–10, 1959
Chicago, Ill.

Linde Expands Nitrogen Facilities

New nitrogen supply facilities have been put into operation in Houston, Texas and Tulsa, Oklahoma by Linde Co., Division of Union Carbide Corp. The new units are known as VST installations and will be used to store large quantities of liquid nitrogen. Added to Linde's nitrogen producing center at Houston, the new units are said to provide a network of distribution facilities that now makes nitrogen readily available to consumers of all sizes in the Gulf Coast area.

The installation at Houston has a capacity of more than 1 million cubic feet of nitrogen while the capacity of the new Tulsa installation is slightly less than 1 million cubic feet. Both units will be filled by railroad tank cars from Linde's nitrogen producing plant in Houston.

ENGELHARD INDUSTRIES ENLARGES SCOPE

Flanked by Charles W. Engelhard (left) board chairman, and Gordon W. Richdale, president, Ben Grauer presides at a recent show at New York's Waldorf-Astoria marking the formation of Englehard Industries, Inc., the largest fabricator of precious metals in the world. The show was followed by a 5300-sq ft exhibition of the company's products. With gross annual sales exceeding $200 million, the new firm is among the 200 largest industrial companies in the United States. The American Platinum Works, Newark, N. J., was among the firms incorporated

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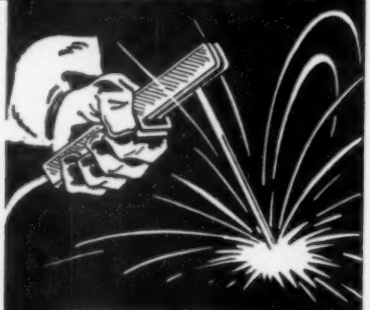

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NCG Appoints Camden Dealer

Antrim Welding Supply Co., 1514 Federal St., Camden, N. J., has been appointed an NCG industrial gas dealer and Rego flame-cutting and welding equipment franchise distributor by the NCG Division of the Chemetron Corporation, Chicago.

Establishment of the new supply company as a subsidiary is a diversification move by Antrim Hardware Co., Camden mill supply firm.

Handy & Harman Elects Townsend

M. W. Townsend has been elected vice president for administration and finance of Handy & Harman at a meeting of the board of directors on April 17th.

Mr. Townsend joined Handy & Harman in 1946, becoming, in turn, assistant to the vice president in charge of sales, and sales manager. He was appointed assistant to the president in 1953. Two years later he became a director of the company. A Phi Beta Kappa graduate of Wesleyan University, he received a B.A. degree in 1934.

Near Record Sales for M & T

Consolidated net sales of Metal & Thermit Corp. for the year ended Dec. 31, 1957, held at near-record levels of $42,200,580, compared with the all-time record of $42,222,677 established in 1956, H. E. Martin, president, told shareholders in the Annual Report recently.

The level of gross profit margins was generally maintained in most lines.

Consolidated net income for 1957 amounted to $1,461,351, equal, after preferred dividends, to $1.82 per share on the 792,550 shares of common stock outstanding at Dec. 31, 1957.

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BURDETT OXYGEN CELEBRATES 35th ANNIVERSARY

William H. Loveman, president of the Burdett Oxygen Co. of Cleveland, Ohio, cuts the first slice of a 63-lb, cylinder-shaped cake to celebrate the firm's 35th anniversary. Looking on (*left to right*) are Dorothy Bader, Jack Oberst, Norman Carl, J. F. Wagner, Harold Scherl, Eugene J. Morse, Morris Richman, Rose Gallagher and S. Michael Loveman

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without valve damage

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TUBE-TURN LIGHT WEIGHT TAPER FACE FLANGES

The new TUBE-TURN* 125 lb. light weight, forged steel, taper face welding neck flanges (patent pending) can cut costs three ways:

1. You eliminate the hazard of breaking cast iron and semi-steel valves, fittings and equipment such as pumps and compressors, caused by overstressing the bolts to get a tight seal when regular ASA steel flanges are used.
2. You avoid the necessity of using more expensive 250 lb. valves with 300 lb. companion flanges.
3. The new flanges cost less, weigh less and take less storage space than the 150 lb. flanges they replace.

Maximum service pressures are the same as for Class 125 cast iron flanges in ASA B16.1, namely: 125 psi (gage) saturated steam; 175 psi (gage) liquid and gas (WOG) at 150°F.

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How TUBE-TURN® Taper Face Flanges give you a tighter seal without overstressing

TUBE-TURN taper face forged steel welding neck flanges conform to the 150 lb. American Standard with respect to flange diameter and drilling, but both the flange ring and tapered hub are thinned to make them compatible in strength and stiffness to Class 125 American Standard cast iron flanges with which they are mated.

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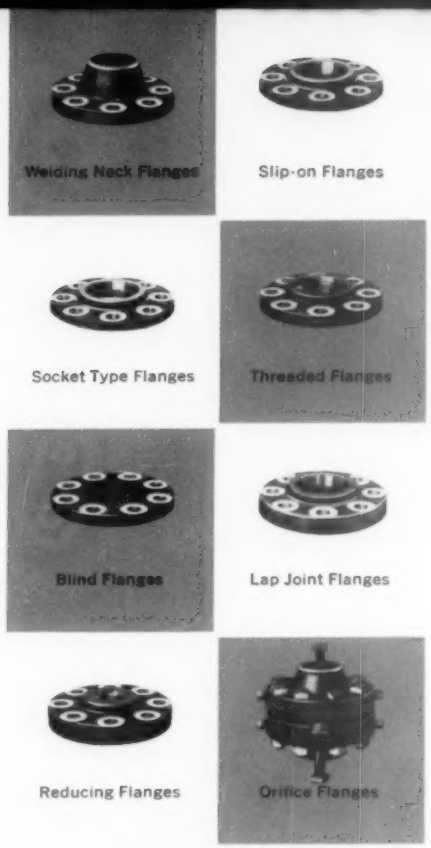

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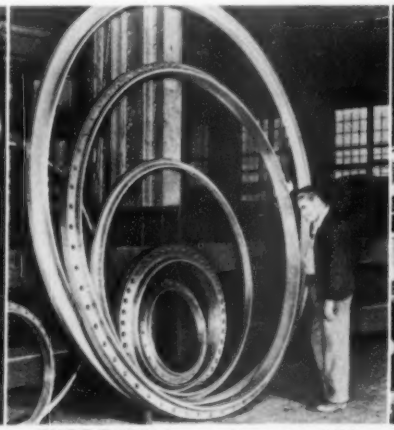

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INTERNATIONAL WELDING NEWS

By Dr. Gerard E. Claussen

Austrians Honor Rosenberg

The Austrian Welding Society[1] celebrated the 85th birthday of Dr. Emanuel Rosenberg on Nov. 28, 1957. Dr. Rosenberg invented the cross-field welding generator in 1904. The Elin-Rosenberg cross-field generator, with minor changes, is in use throughout the world today. Besides his interest in welding machines he promoted the application of arc welding to steel structures. In 1928, at an Elin factory in Weiz, Dr. Rosenberg was responsible for the first welded railroad bridge in Europe. The span of the plate girder bridge was 30 ft and it weighed 9 tons. The bridge was designed for riveting, for which welding was substituted. Dr. Rosenberg, a former director of Elin, is living in retirement in Bogota, Colombia.

Russian Exposition

A great deal of welding equipment was exhibited at the Russian Manufacturers Exposition[2] in 1957. Among a large number of products on exhibit were: (1) manual and automatic equipment for cold pressure welding, (2) an ultrasonic soldering outfit operating at 18 to 22 kilocycles on the magnetostriction principle; (3) a submerged-arc flux for d-c and a-c welding of mild steel in the field (the flux contains 54% manganese ore, 7% fluorspar, 30% quartz sand, 7% ferrosilicon and 2% aluminum powder; the weld metal has good impact properties down to −30° F); (4) a universal machine for electro-slag welding of steel from 18 to 63 in. thick at a maximum current of 1000 amp, (5) a flux consisting of fluorides and chlorides of alkalis and alkaline earths for submerged-arc welding of titanium, and (6) a CO_2 welding apparatus for depositing up to 15 lb of steel per hour.

Argentine Welding Magazine

The magazine *Sol-Oerlikon* has completed its first year of publication. It is edited in Mendoza in Western Argentina by five industrial firms. The last issue describes a welded 2800-ton floating drydock and has instructional articles on welding distortion and continuous welded rails.

Swiss Standard on Resistance Welding

The Swiss Society of Machinery Manufacturers (VSM)[3] issued a tentative standard, "Directives for the Design of Spot Welds in Aluminum and Its Alloys." The standard prescribes minima for spot diameter ($2T + 3$ mm), spot spacing ($6T + 15$ mm) and edge distance ($3T + 7.5$ mm), where T = sheet thickness in millimeters. Sketches of recommended shop practice are given as well as tables of recommended spot sizes and spacing with expected strength for aluminum and three alloys (Al-Mn, Al-Mg and Al-Zn-Mg-Cu). A Russian paper[4] provides tables for computing the temperature distribution in bars of mild and stainless steels 1/4 to 1 3/4 in. diam during resistance butt welding. The method of calculation takes into account changes in conductivity with temperature, and the calculated results agree with actual measurements.

Brittle Fracture in Germany

The new standard specification for structural steel in Germany (DIN 17100) divides steels of the same strength into classes based on notch impact test results. To assist designers in selecting the proper class of steel the German Structural Steel Committee[5] issued tentative recommendations based on extensive tests. Quality numbers were assigned to every material, the four quality groups being:

Group 1	Z = 1 to 14
Group 2	Z = 15 to 21
Group 3	Z = 22 to 26
Special steel	Z = 27 and over

The higher the quality of the steel, the higher is the quality number Z. The quality numbers are derived by the designer from a consideration of seven factors:

A. Effect of longitudinal shrinkage stresses.
B. Static load stress.
C. Sensitivity to fabrication.
D. Thickness.
E. Cold work.
F. Low temperatures.
G. Consequences of accidents.

One point is added to Z for every 5° C decrease in notch impact transition temperature. For every 5 mm increase in thickness which does not raise the transition temperature, an additional point is added. Numerical values have not been suggested for the less tangible of the seven factors, for example, *G*.

A brittle fracture that occurred in the web of a 20-in. I-beam 30 years old starting at 50° F from a flame cut made during demolition was examined by Felix and Geiger.[6] The steel contained 0.09 C, 0.52 Mn, 0.093 S, 0.058 P, 0.01 Si, 0.016 N_2 and had transition temperatures of 77, 104 and 158° F, respectively, in the Swiss notch text, Charpy V test and sharp notch tests. Microhardness measurements showed higher values for grains that heat tinted dark than for grains that heat tinted light. The response to heat tinting was related to the grain orientation, which supported the hypothesis that deformation of ferrite crystals in brittle fracture depends on their orientation.

Brazing Discussed in Hanover

A thesis presented to the Hanover Technical College by Colbus[7] discusses results of temperature measurements made just below the surface of beads deposited on steel, stainless steel, cast iron, copper, brass and aluminum. The beads were deposited with an oxyacetylene flame from a rod of the same composition as the plate. It was found that the rod must be molten in order to achieve a bond with the plate. The temperature of the plate required to achieve a bond with the molten rod depended on thermal conductivity. The requisite plate temperature varied from 76% of the rod temperature for stainless steel, which has low conductivity, to nearly the same as the rod temperature for copper. The results are said to show that joining of metals of low conductivity is possible at temperatures well below their melting point using molten drops from a rod of the same composition.

Low-Hydrogen Electrodes in Austria

A thorough review of practical welding procedures with low-hydrogen electrodes in Austria is given by Schmidt.[8] He emphasizes the importance of avoiding undue exposure of the arc to air in any manipulation of the electrode and states that the higher the percentage of alloying elements in the coating, the more difficult it is to assure uniform composition of deposit. In repairing a cracked cast-steel press frame 10 in. thick, he placed a 1/2-in. copper bar at the root to prevent propagation of the unchipped root portion of the crack. The copper bar functioned in the same way as holes drilled at the end of the crack to prevent spread.

A Russian writer[9] found that the de-

Dr. Gerard E. Claussen is associated with the Linde Co., Newark, N. J.

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gree of oxidation of a low-hydrogen electrode coating is increased by calcium carbonate and was decreased by calcium fluoride and by substitution of nonoxidizing oxides for calcium carbonate. An increase in the ratio of CaO to SiO_2 increased the recovery of manganese but decreased the recovery of silicon.

Arc Welding Behind the Curtain

A study[10] of arc pressure in inert-gas and submerged-arc welding of steel showed that arc force, apart from the electromagnetic component due to the geometry of the measuring apparatus, was proportional to welding current. The force was 30% greater at the same current for submerged-arc welding than for consumable-electrode welding in argon, the deposition rate being less for the latter process. Tungsten-electrode welding produced 25% less force than consumable-electrode welding in argon. Typical values of the force in milligrams at 120 amp were 650 for electromagnetic effect alone, 850 for tungsten-electrode welding, 1100 for consumable-electrode welding in argon and 1500 for submerged-arc welding. Lengthening the arc reduced the arc force for consumable-electrode welding in argon.

The rate of transfer of globules of metal across the arc with covered electrode was measured by a Russian laboratory[11] using oscillograms. Certain electrodes showed infrequent short circuits, 3 to 5 per second, whereas others showed 20 shorts per second. One of the electrodes used in this study was the well-known Fleetweld 5. Charts for deriving time-temperature relations for heating and cooling of steel plates 0.16 to 0.32 in. thick in open-arc welding at 110–240 amp are given by Havalda,[12] of the Czech Academy of Science. The charts are based on thermocouple surveys and are useful, in conjunction with TTT diagrams, in estimating the extent of hardening of high-tensile steels during welding.

Heat-Resistant Steels

Weigand[13] shows that the necessity for using a small amount of ferrite in weld metal for austenitic heat-resisting steels of the 16% Cr – 13 to 20% Ni type to avoid cracking entails a loss of toughness after 1000 hr at 1000 to 1300° F. Aside from avoidance of sulfur, phosphorus and silicon, he has no solution except careful welding procedure. The CO_2 welding of steels up to $1^3/_{16}$ in. thick, containing 0.04 C, 0.60 Si, 0.90 Mn, 1.30 Cr, 0.4–0.9 V, 0.8–1.0 Mo, 0.04–0.45 Al, is described by Russian writers.[14] The electrode contained 0.10 C, 0.7–0.9 Si, 1.0–1.3 Mn, 0.95–1.25 Cr, 0.3–0.4 V, 0.5–0.7 Mo, 0.025 S max, 0.03 P max, 0.25 Ni max. Interpass temperature was not less than 610° F, and joints were stress relieved 7 hr at 1270–1310° F. The creep strength of weld metal was equal to base metal, being 22,000 psi for 100,000 hr at 1000° F. Welding conditions were 300–320 amp, 42 cfh CO_2. Compared with manual covered electrodes the cost per pound of deposited metal with CO_2 was reduced by a factor of 1.5 to 1.7.

Welding conditions for transformer steels (0.7, 2.3 and 4.3% Si) 0.014 and 0.020 in. thick were worked out by Ruge and Rauchfuss[15] using a tungsten electrode inclined 25 deg forward, argon shielding and backing gas and grooved copper backing. The welding speed had to be controlled exactly to secure sound welds. Welds annealed at 1700° F had nearly as good magnetic and mechanical properties as those specified for unwelded steel.

Hundreds of thousands of tons of welded plate girders[16] up to 6 ft high are used in Russia every year. Since it is cheaper to weld I-beams of this size rather than roll them, a production line was set up. The web-flange weld was the bottleneck in the line. Three-electrode submerged-arc welding reduced the production time to the extent that a 39-ft girder was produced every 12 min. Two shifts produced 20,500 girders in a year. The welding speed in three-electrode welding was 33 to 102 ipm, the width of weld at the highest speed being about $^3/_4$ in.

Hard-Surfacing Materials

A book from Argentina on combating wear by arc welding* discusses 14% manganese steel, in particular, but also deals with other hard-surfacing materials. The author leans heavily on the literature but, at the same time, presents the results of extensive micrographic, tensile and wear tests. In general, the test results confirm previous literature.

Book Reviews

Three titles† have been added recently to the list of 12 books on welding topics published by the German Welding Publications Co. in collaboration with the Vieweg firm that publishes the German Welding Society's magazine. Volume 6 is a small leaflet on the design of welded eyebars for vehicles moving at a speed of over $12^1/_2$ miles per hour. The materials suitable for eyebars are described, and the method of calculating allowable stresses in welds is outlined. Volume 7 is a collection of papers read at the Hanover Welding Convention in 1956. The papers discuss welding in Russia, hard surfacing, welded machine tools, flame hardening, welding of tools and repair welding. Volume 8 is a small textbook on ferrous welding metallurgy. The six chapters deal with the iron-carbon diagram, mild steels, low-alloy steels, heat- and corrosion-resistant steels and cast iron.

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† Volume 6, *Hinweise für Das Schweissen von Anhänger-Zuggabeln*, 14 pp., 8 illustrations, 1.20 German marks (1957).

Volume 7, *Vorträge der Grossen Schweisstechnischen Tagung*, Hannover 1956, 68 pp., 186 illustrations and tables, 6 marks (1956).

Volume 8, *Kleine Werkstaffkunde für das Schweissen von Stahl und Eisen*, by H. Lueb, 96 p., 52 illustrations, 9.80 marks (1957).

The publisher of these three volumes is: Deutscher Verlag für Schweisstechnik, GMBH, Fried. Vieweg & Sohn, Burgplatz 1, Braunschweig, West Germany.

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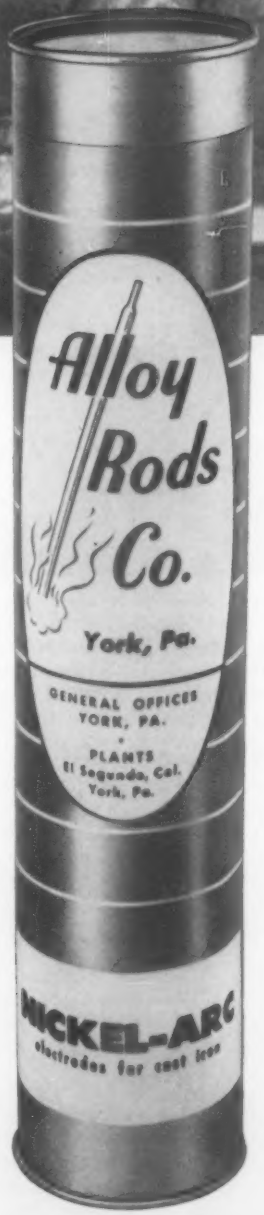

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PERSONNEL

Ronay Named by Gulton

Appointment of Bela M. Ronay AWS, as a consultant in welding technology to Gulton Industries, Inc., Metuchen, N. J., was announced recently by Leslie K. Gulton, president.

Mr. Ronay's services will be concentrated chiefly about the welding research activities of the company's Advanced Development and Systems Department.

Born and educated in Hungary, Mr. Ronay has been a consultant in welding with specific emphasis on design and fabrication of atomic reactors and associated equipment since 1956. Previously, he was superintendent of the U. S. Naval Engineering Experiment Station, Annapolis, Md., for 25 years.

Mr. Ronay holds over 20 patents in his specialty and is the recipient of the Distinguished Meritorious Award from AWS for his outstanding work for the past 35 years.

Wilson Joins Graver Tank

The appointment of E. J. Wilson, Jr. AWS, as chief welding research engineer has been announced by Graver Tank & Mfg. Co., Inc., East Chicago, Ind. In this capacity he will report to A. R. Meyer, director of welding research.

Mr. Wilson is a graduate of the University of Notre Dame and has been associated with the Oak Ridge National Laboratory and Westinghouse's Headquarters Metals Joining Laboratory. He is also a member of the American Society of Metals and the American Nuclear Society.

Mabb Named Chief Engineer

Chapman Valve Manufacturing Co., Indian Orchard, Mass., has appointed William S. Mabb AWS, to the post of chief engineer. A graduate in mechanical engineering from Rensselaer Polytechnic Institute, Mr. Mabb has been associated with Chapman Valve since 1937. During 1956–57 he served as secretary of the Western Massachusetts Section of the AMERICAN WELDING SOCIETY.

Franz Promoted

Raymond J. Franz AWS, has been promoted to the position of chief welding engineer of shops at the plant of Graver Tank & Mfg. Co., Inc., in East Chicago, Ind.

Lell Promoted by Wall Colmonoy

Appointment of Elmer J. Lell AWS, as vice president in charge of Colmonoy Division operations is announced by W. P. Clark, president of Wall Colmonoy Corp., Detroit.

Mr. Lell joined Wall Colmonoy in 1948 as midwest sales engineer. He was

Elmer J. Lell

named branch manager of the company's Houston, Tex. office in 1950. He returned to the Detroit office in 1951 and served successively with the Colmonoy Division as service manager, assistant sales manager, sales manager and vice president—sales prior to his new appointment.

Mr. Lell studied mechanical engineering at UCLA.

Downs Appointed Zone Manager

Fred S. Downs AWS, has been appointed zone manager, Railroad Sales, Eastern Region, Air Reduction Sales Co., succeeding C. B. Armstrong who retired after 37 years of service.

Fred S. Downs

Mr. Downs joined Airco in 1935 serving in such capacities as salesman and railroad sales representative in the Boston and New York City-New Jersey areas.

Lester Appointed Welding Engineer

Appointment of William J. Lester AWS, as welding engineer for Alloy Fabricators, Inc., El Monte, Calif., is announced by Hugo W. Hiemke AWS, president.

For the past five years, Mr. Lester was with C. F. Braun & Co. as research engineer and as manufacturing division welding engineer. Prior to that he held responsible positions in metallurgical and sales engineering work in Canadian industry. He is a graduate of the University of Toronto in metallurgical engineering.

William J. Lester

With Alloy Fabricators he will be concerned with the manufacture of heat- and corrosion-resistant pipe, heat-treating furnaces and fixtures and alloy weldments.

New Post for Thompson

Magnesium Co. of America, East Chicago, Ind., has announced the appointment of Charles L. Thompson as general sales manager of the corporation.

Mr. Thompson has been manager of sales for the Aluminum Extrusion and Tubing Division of Reynolds Metals Co.; general manager of the Buda Engine and Equipment Co.; and general sales manager of Material Handling Equipment, Allis-Chalmers Manufacturing Co.

Cruse Made Sales Manager

Appointment of F. R. Cruse AWS, as sales manager for the Stainless Processing Division of Wall Colmonoy Corp., Detroit, is announced by R. L. Peaslee AWS, vice president in charge of the division.

F. R. Cruse

Mr. Cruse, a mechanical engineering graduate of Indiana University, joined Wall Colmonoy Corp. in 1952 as a sales engineer for the Stainless Processing Division. In 1956 he became assistant sales manager, a position he held until his new appointment.

Pannier Appointed

Georges L. Pannier has been appointed consulting engineer for the Metallizing Co. of Los Angeles, Inc. He was formerly associated with Kennecott Copper, developing processes to produce titanium metal, and with P. M. Corp., at Burlington, Vt., doing research and development work with titanium, zirconium, uranium and cermets.

Jacklin Promoted by Miller

As part of the expansion program of Miller Electric Manufacturing Co., Inc., Appleton, Wisc., Gordon Jacklin AWS, was selected for the firm's recently created post of assistant to the vice president under C. B. Abel AWS, vice president in charge of sales.

Mr. Jacklin began work at Miller in July of 1951. From assembly work he advanced to the Service and Repair Department and later to a job as sales correspondent.

Gordon Jacklin

Crockett Named by Airco

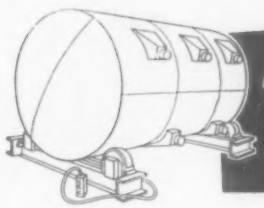
J. M. Crockett, assistant to vice president—gases of Air Reduction Sales Co., has been appointed manager of the Birmingham District as of April 1st, it was announced by H. C. Wallace AWS, regional sales manager, Southern Region. Mr. Crockett replaces W. L. Poole AWS, who has been named sales consultant for the Birmingham District.

Mr. Crockett began his association with Air Reduction in 1945 as an assistant metallurgical engineer. He has held various management positions in the New York office of the company.

Soyka Joins Eutectic

Appointment of Fred R. Soyka as director of purchases has been announced by René D. Wasserman, president of Eutectic Welding Alloys Corp., Flushing, N. Y.

A mechanical engineering graduate of the University of Toronto in Canada, Mr. Soyka was previously associated with Aluminum Co. of Canada, as purchasing agent of chemical equipment.



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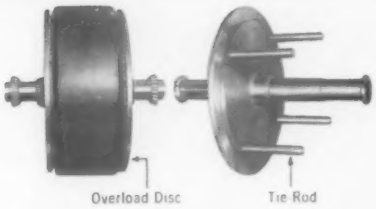

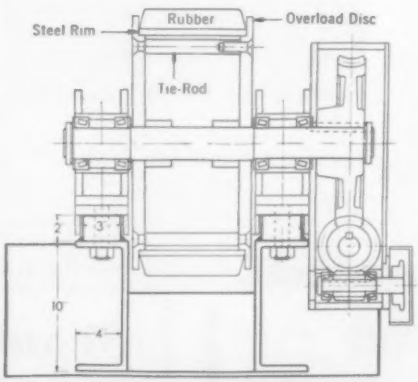

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Thoma Promoted by Airco

A. J. Thoma, controller of Air Reduction Co., Inc., has been elected vice-president and controller. Mr. Thoma has been controller of the company since 1950.

Strouse and Ellison Appointed

Tom Strouse, formerly district sales manager of the Liquid Carbonic Division of General Dynamics Corp., has

Tom Strouse

Robert Ellison

been appointed general sales manager of industrial-medical sales in the East Central Region. Mr. Strouse will manage sales at their locations in Detroit, Cleveland, Urbana and Cincinnati with offices in Cleveland, Ohio.

Robert Ellison [illegible], formerly of O. E. Meyer & Sons, Inc. and Metal & Thermit Corp., will replace Mr. Strouse as district sales manager at the Cincinnati plant.

Stewart Joins Distributor

Lowry L. Stewart became associated with Valley Welders Supply Co., Albuquerque, N. Mex., on April 1st to work general sales and handle sales management.

Mr. Stewart has been in the welding supply business 25 years, with 10 of these years being spent with Air Reduction Sales Co.

Rasmusen Joins Miller

Miller Electric Manufacturing Co., Inc., Appleton, Wisc., announces the appointment of Reidar P. C. Rasmusen as electrical engineer.

An honor graduate in electrical engineering from North Dakota State College, 1940, Mr. Rasmusen is a member of the American Institute of Electrical Engineers and has served as chairman of the AIEE subcommittee on resistance welding instrumentation, and vice chairman of the AIEE committee on electric welding.

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OBITUARY

Lydia Punnett Wasserman

Mrs. Lydia Punnett Wasserman, wife of René D. Wasserman, president of Eutectic Welding Alloys Corp., New York, died Saturday, March 15th, as a result of injuries received in an automobile accident on Long Island.

Born in Salonika, Greece, in 1929, Mrs. Wasserman was educated in France and England. Before her marriage to Mr. Wasserman, June 11, 1956, she was a public relations specialist in England.

Residents of 60 Sutton Place South, New York, the Wassermans celebrated the birth of their son, Christopher Hugh, on February 7th.

Mrs. Wasserman was a member of the board of directors of Eutectic.

Erich M. Hofmann

Erich M. Hofmann, second vice-president of the Cleveland Engineering Society and president of E. Hofmann Engineering Co., consultants and designers of special machinery and equipment, died suddenly at Cleveland Clinic Hospital October 24th. He was 57.

Born in Dresden, Germany, Mr. Hofmann came to Cleveland 34 years ago. Before he founded his own business he was associated with White Motor Co.,

WELDING ENGINEER

Career position for graduate engineer with 2-4 years' extensive metallurgical and welding background. Diversified assignments in research projects of welding, formings, and physical properties including metallographic studies and diagnosis of failures. Must be thoroughly familiar with code welding requirements. Location will be metropolitan N. J., with a leading designer/manufacturer of steam generating and heat transfer equipment. Forward complete resume including salary requirement to:

BOX V-355

Wanted:

Travelling District Sales Manager, resident of San Francisco area, to sell and service distributors and customers in Northern California for leading producer of reclamation welding products for the repair of equipment subject to impact and abrasion. Welding experience desirable.

Box V-356

Warner Co., General Electric Co. and Speedline, Inc.

Mr. Hofmann was a member of the AMERICAN WELDING SOCIETY and the American Society of Tool Engineers.

Charles Kandel

Charles Kandel, founder and president of the Craftsweld Equipment Corp., Long Island City, N. Y., died at his home in Jackson Heights on April 21st. He was 69.

Mr. Kandel migrated from Rumania to this country in 1900 and received a degree in civil engineering from Columbia University in 1911. He entered the welding industry in 1917 as a construction engineer involved in the design and supervision of numerous Navy and industrial plants for producing oxygen, hydrogen and acetylene. Mr. Kandel became founder and president of Craftsweld Equipment in 1927. The firm manufactured welding and cutting equipment, diving gear and pioneered in underwater cutting and welding equipment. Among the inventions credited to him are the Kandel arc-oxygen torch and the Craftsweld loudspeaker diving telephone for multiple divers.

The author of articles published in THE WELDING JOURNAL, Mr. Kandel was a past chairman of the New York Section of the AMERICAN WELDING SOCIETY.

George Vincent Slottman

George Vincent Slottman, fifty-four, vice president—research and engineering of Air Reduction Co., Inc., died on April 21st at Memorial Hospital after a brief illness. He resided at 1 University Place, New York City.

George V. Slottman

Dr. Slottman was born in New York City and graduated with a B.S. degree from the Massachusetts Institute of Technology in 1925, and with a Ph.D. from the University of Berlin in 1927.

From 1927 to 1930 he was professor of chemical engineering at the Massachusetts Institute of Technology. In 1930 Dr. Slottman joined the United Steel Companies Ltd., Sheffield, England, as chief combustion engineer and iron works manager. He joined Air Reduction in 1934 as manager of the technical sales division, and in 1949 became director of research and engineering. His appointment as vice president was made in 1952.

Dr. Slottman, since 1924 directly associated with the development of oxygen-cutting processes, was an active member of a dozen engineering societies including the AMERICAN WELDING SOCIETY, the American Rocket Society, the American Iron and Steel Institute and the Industrial Research Institute.

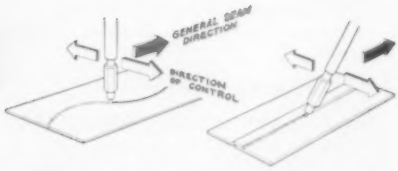
In 1955 he was presented the James Turner Morehead Medal by the International Acetylene Assn. for his scientific contributions to carbide, acetylene and oxygen technology.

8101-LWE

New concept in fully automatic welding creates savings in labor, tooling and set-up costs because . . .

Electronic Device Tracks Weld Seams Automatically

Automatic D.C. welding heads almost think for themselves when harnessed to a newly developed seam tracing device. This extraordinary self-guidance system makes *fully automatic welding possible for the first time.* LADC (Lewis Automatic Directional Control) seeks, follows and welds accurately on straight, curved or irregular seams. Its two-directional action maintains constant weld seam centerline positioning without operator guidance.



2-Directional movement keeps head centered on seams.

LADC welding random curved seam in 3/8" mild steel (submerged arc).

When used in conjunction with specially adapted Lewis head manipulators, LADC simplifies automatic welding operations . . . reduces labor and errors to minimum. This versatile control device eliminates special tooling and time-consuming set-up or alignment. It can be used for downhand butt, groove, lap or fillet welds, and is especially effective for internal welds in cylindrical fabrications.

For complete details and prices, write today or call BEdford 2-2500. **The Lewis Welding & Engineering Corp., 109 Northfield Road, Bedford, Ohio.**

For more details, circle No. 23 on Reader Information Card

NEW LITERATURE

New Revised AWS Specification on Safety in Welding and Cutting

This is a complete 49-page revision of the AWS-ASA Z49 standard wherein the entire field is covered in detail. Fire Prevention and Protection indicates the basic precautions to be taken and also the additional precautions necessary when the nature of the work is within certain categories. Fire statistics indicate that when these recommendations are observed, fires do not occur.

Protection of personnel is covered extensively and includes the precautions necessary when using the newer welding processes. Eye protection is particularly stressed and recommendations are made for adequate shielding from flying particles and harmful rays. The precautions necessary when welding with inert gases are fully detailed and suggestions are made for the protection of fellow workers.

Health protection and ventilation have been based upon three factors: dimensions of working space, number of welders and evolution of hazardous contaminating agents. Recommendations are given as to the precautions necessary to give adequate ventilation and health protection to personnel.

Considerable space is devoted to the safe handling of fuel gas and oxygen cylinders. Certain provisions are mandatory, others are recommended as good practice and some, which have been tested by a nationally recognized testing agency, are regarded as acceptable.

This standard may be obtained from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y., at $2.00 per copy.

Semiautomatic Welder

Six-page Bulletin 5205.1, released by the Lincoln Electric Co., Cleveland 17, Ohio, describes the manufacturer's Model ML-3 "mechanized squirt welder." Lincoln reports that the new unit combines the advantages of automatic submerged-arc welding with the versatility of manual arc welding. The manufacturer also states that the Lincolnweld SA-750 is the only power source recommended for use with the Model ML-3 unit. The unit is said to provide faster deposition rates, deeper penetration, less distortion, improved operating factor and scrap reduction.

For your free copy, circle No. 24 on Reader Information Card.

Flame-Cutting Machines

A complete line of Oxweld flame-cutting machines is described in a 28-page catalog available from Linde Co., Division of Union Carbide Corp., 420 Lexington Ave., New York 17, N. Y.

Also included are complete specifications for each machine, illustrations of typical installations, and a description of machine accessories such as automatic and magnetic tracing units.

For your free copy, circle No. 25 on Reader Information Card.

Resistance-Welding Applications

Bulletin No. 341 from Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill., describes certain special applications in resistance-welding machinery, including multiple-gun spot welding, multiple-gun projection welding, mash welding, seam welding and cross-wire welding with either standard or special welders.

For your free copy, circle No. 26 on Reader Information Card.

Booklet on Welding Industry

On Sept. 17, 1957, a talk was presented before the Eastern Zone Regional Meeting of the National Welders Supply Association by Robert M. Rohrberg, office of the vice president—sales of the Air Reduction Co., Inc. Entitled, "Growth and Development of the Welding Industry," the talk has been reproduced in a 15-page booklet by Airco and is available to the public. Analysis is given to such questions as vertical growth, horizontal growth, internal growth, future economic growth factors, welding markets and welding's future.

For your free copy, circle No. 27 on Reader Information Card.

Carbon-Arc Compressed-Air Cutting

Bulletin DM-72 from Hobart Brothers Co., Troy, Ohio, tells how a large foundry reduced cleaning room costs with carbon-arc compressed-air cutting equipment. Pictures show the step-by-step method of finishing castings in this plant.

For your free copy, circle No. 28 on Reader Information Card.

Brazing Manual

A new 28-page booklet for self-instruction and in-class or on-the-job training in metal joining (28 pp., 4 x 7 in.) has been published by All-State Welding Alloys Co., Inc. Entitled *"Brazing Manual"* the 4 x 7 in. publication is particularly addressed to the service trades. It contains illustrated data for brazing shapes, sheet, castings, tubing and assemblies of copper, brass, steel, aluminum and cast iron.

For your free copy, circle No. 29 on Reader Information Card.

Aluminum

Sheet and Plate Product Information, a 320-page, illustrated book prepared by the Technical Publications Department of Kaiser Aluminum & Chemical Sales, Inc., Chicago 11, Ill., is available without cost if requested on company letterhead; otherwise a charge of $5.00 is made.

The subject of aluminum sheet and plate has been comprehensively treated in this new book. The material includes a wide range of data on aluminum and its alloys.

The well-illustrated volume of 320 pages is designed to inform the reader of aluminum's characteristics and its practical applications for a variety of sheet and plate fabricated parts and assemblies.

The purpose of the book is twofold: (1) to describe aluminum and its alloys as a metal, how it is made, its availability, and the metal's physical and chemical attributes and (2) to impart to the reader the basic facts which will be helpful in the proper selection and use of aluminum sheet and plate alloys, for various methods of aluminum fabrication and finishing.

Welding Fittings

A new 4-page folder has been released by the Tubular Products Division of the Babcock & Wilcox Co., Beaver Falls, Pa. This folder, known as Bulletin FB-503, explains the proper ways to prepare the requisition or order for welding fittings and flanges. By following the suggestions in this folder, the buyer can be sure that the supplier will understand what he requires.

For your free copy, circle No. 30 on Reader Information Card.

Surfacing News

Volume 3, No. 2 of "Colmonoy Alloy News," published by Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich., is now available for distribution. The six articles in this March-April issue cover such subjects as the surfacing by metal spray on cutter head shafts; the success of Wall Colmonoy's speakers' bureau; maintenance surfacing in a Canadian refinery; the counter action of corrosion galling; the surfacing of plungers used in boiler feedwater pumps and a description of the manufacturer's "spraywelder units."

For your free copy, circle No. 31 on Reader Information Card.

Steam Trap Data

A $3^{7}/_{8}$- x $8^{1}/_{2}$-in. data card entitled, "Something New in Trap Maintenance," is now available from Tempil® Corp., 132 W. 22nd St., New York 11, N. Y. The colored pocket guide includes steam trap data showing the steam temperature expected to occur below a normally functioning trap for a given steam supply pressure.

For your free copy, circle No. 33 on Reader Information Card.

Glass-to-Steel Welds

The Taylor-Winfield Corp., Warren, Ohio, has published issue No. 581 of "Weld-It." Described in the four-page folder is a resistance-welding technique engineered by the Ohio concern to join electrical connector tabs to terminal pins at the plant of the Fusite Corp. Resistance-welding installations at other companies within the refrigeration industry are also discussed.

For your free copy, circle No. 34 on Reader Information Card.

Powder Lancing

A new 8-page booklet describing typical powder-lancing applications is available from Linde Co., Division of Union Carbide Corp., 420 Lexington Ave., New York 17, N. Y. In addition to giving a brief history of powder lancing, the illustrated booklet shows how this process is utilized in the steel and construction industries on jobs that would otherwise be time-consuming or economically impossible.

Case histories are cited in which powder lancing saved valuable steel-producing time in furnace maintenance work, such as tapping open-hearth slag pockets and blast-furnace salamanders, and cleaning up spill-out debris. Other case histories show how powder lancing is used to shape and demolish thick concrete in situations where conventional demolition methods cannot be employed.

For your free copy, circle No. 35 on Reader Information Card.

Fire Prevention

The December 1957 issue of "Arc and Flame," Vol. 7, No. 4, is now available from Canadian Liquid Air Co., Ltd., 1111 Beaver Hall Hill, Montreal, Quebec. The feature article describes some of the fire precautions taken by the various employes at Montreal Transportation Commission. Other articles in the four-page folder discuss iron-powder electrodes, pipe-cutting machinery, repair of bronze propellers and uses for gasoline-driven motor-generator welders.

For your free copy, circle No. 36 on Reader Information Card.

Preforms

Bulletin 114 describing Epoxweld 100 preforms, a new single component epoxy preform used in automatic or production joining, sealing or encapsulating metals, ceramics, glasses and quartz, is available from Duramic Products, Inc., 262-72 Mott St., New York 12, N. Y.

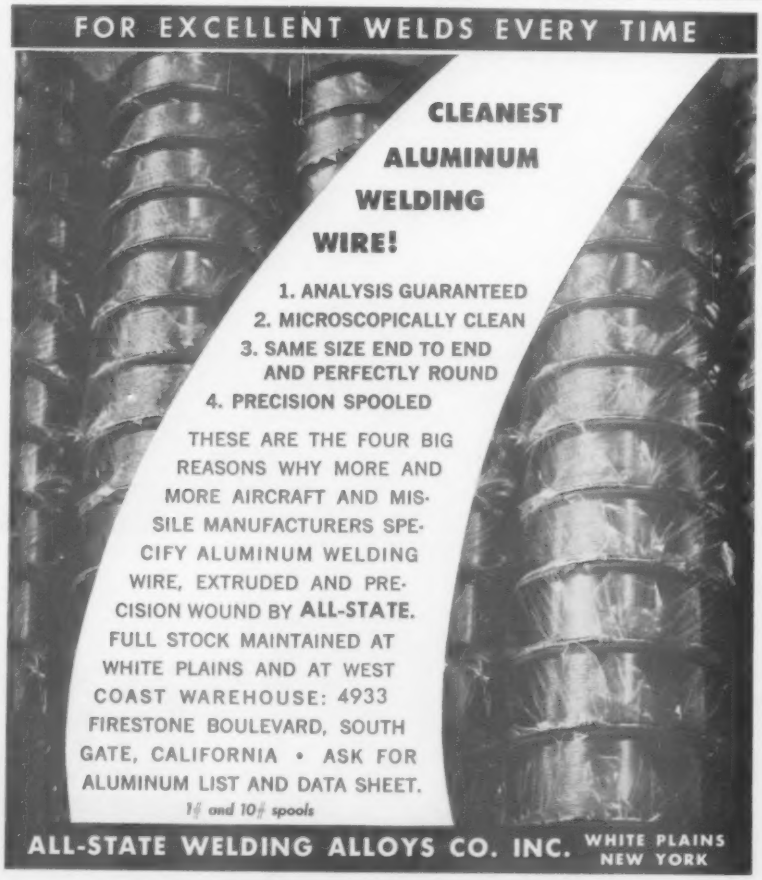
Bulletin 114 is a 2-page bulletin including data on curing temperatures, time cycles, sizes and shapes available, clearances necessary, suggested applications, and a photo of typical Epoxweld preforms.

Epoxweld 100 is an unpolymerized epoxide resin which allows fabricators to introduce a definite shape and amount of epoxy bonding material to accomplish a production assembly.

For your free copy, circle No. 37 on Reader Information Card.

Report on Beryllium

"Beryllium—Present and Potential Uses," a speech delivered before the Atomic Energy Management Conference on March 17th in Chicago, has been reproduced in a 15-page booklet form by the Beryllium Corp., P. O. Box 1462,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CLEANEST ALUMINUM WELDING WIRE!
1. ANALYSIS GUARANTEED
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THESE ARE THE FOUR BIG REASONS WHY MORE AND MORE AIRCRAFT AND MISSILE MANUFACTURERS SPECIFY ALUMINUM WELDING WIRE, EXTRUDED AND PRECISION WOUND BY ALL-STATE. FULL STOCK MAINTAINED AT WHITE PLAINS AND AT WEST COAST WAREHOUSE: 4933 FIRESTONE BOULEVARD, SOUTH GATE, CALIFORNIA • ASK FOR ALUMINUM LIST AND DATA SHEET.
1# and 10# spools
ALL-STATE WELDING ALLOYS CO. INC.
WHITE PLAINS NEW YORK
For more details, circle No. 32 on Reader Information Card

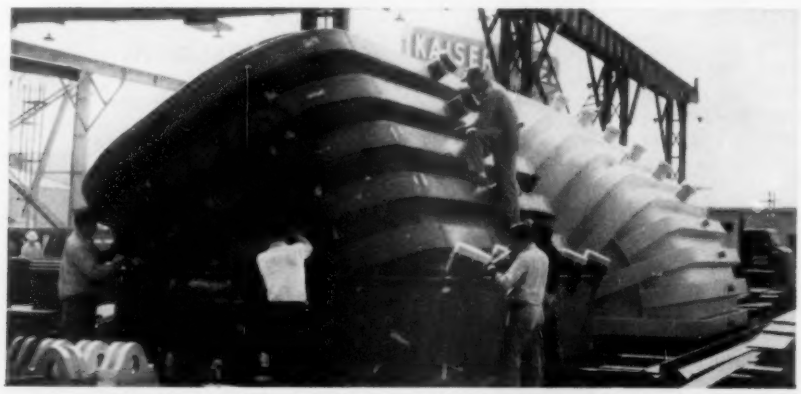
to twist a rocket's tail...

Kaiser Steel's Montebello Fabricating Plant uses A. O. Smith electrodes in fabricating 54-ton flame deflectors that tame the flame in rocket engine tests

When you test a rocket engine, there's literally "hell to pay" in terms of heat, thrust and distortion. To tame the rocket's flame, Kaiser Steel's Montebello plant builds water-cooled, 54-ton flame deflectors. Consisting of 18 individual castings, each deflector requires over 5,000 lbs of electrodes.

Kaiser Steel is using A. O. Smith SW-15 (E-6013) and SW-44 (E-6024) electrodes for the job.

It's just one of many cases in which A. O. Smith can provide the answers to unusual as well as routine welding problems. For more details, contact *your* man from A. O. Smith or write direct.



Half-sections of 54-ton unit requiring over 5,000 lbs. of A. O. Smith electrodes.

The man from A. O. Smith

Jim McKinney is the A. O. Smith representative who worked with Kaiser Steel. More than a salesman, he's a welding specialist, ready and eager to help you with any of your welding problems.

Through research ... *a better way*

A.O.Smith

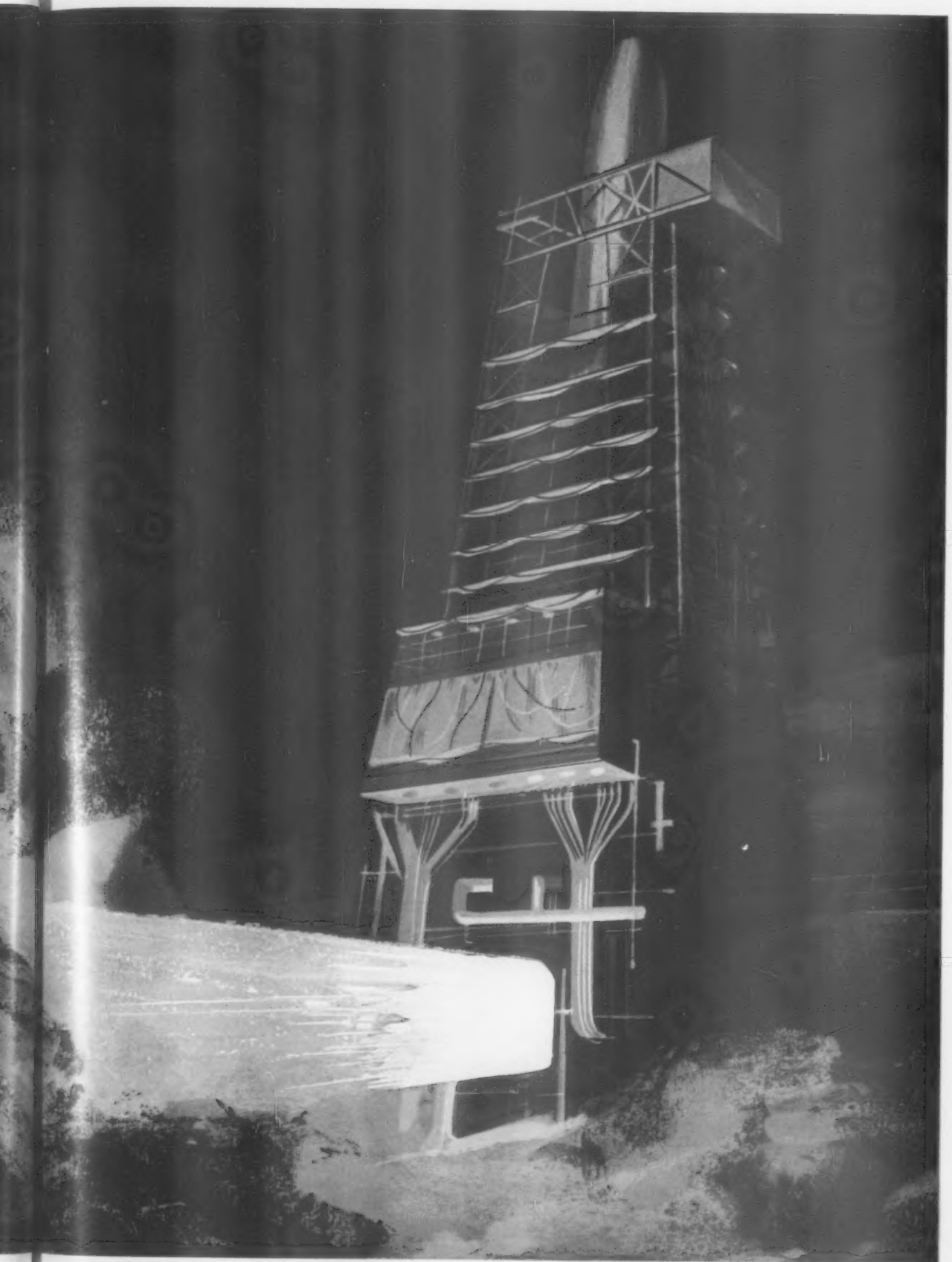
CORPORATION

WELDING PRODUCTS DIVISION

Milwaukee 1, Wisconsin

A. O. Smith INTERNATIONAL S. A., Milwaukee 1, Wisconsin, U.S.A.

For more details, circle No. 38 on Reader Information Card



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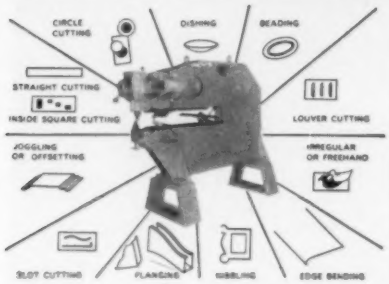
A COMPLETE SHEET METAL SHOP IN ONE MACHINE

PULLMAX

DOES ALL OF THESE OPERATIONS



★ CUTS MILD STEEL UP TO 11/32"

The one machine that's sure to save time, labor and material when you work sheet or plate. Eliminates expensive die costs—easy to operate. 7 sizes to choose from.

Write for free catalog on Metalworking Ideas.

. . . 16mm sound film

. . . or a demonstration right in your plant.

AMERICAN PULLMAX CO., INC.

2467 N. Sheffield Ave., Chicago 14, Ill.

Circle No. 39 on Reader Information Card

Reading, Pa. Authored by Lawrence F. Boland, vice-president of the Reading concern, the text describes such issues as metal, oxide, cost, availability, brittleness, toxicity, need for fabricators and general conclusions.

For your free copy, circle No. 41 on Reader Information Card.

X-Ray on Tough Metals

A new bulletin, describing how Haynes Stellite Co. uses the X-ray spectrograph to determine percentages of elements in alloys, is available from the Instruments Division, Phillips Electronics, Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

The text covers procedures used for 1100 analyses per month involving chromium, tungsten, iron, molybdenum, nickel, cobalt, titanium, manganese and vanadium in concentrations ranging from 1½ to 30% by weight.

Sections of the bulletin deal with sample preparation, selection of standards, and other applications of the X-ray method to special problems. The discussion tells how an analysis is now made in 20 minutes where it formerly took 24 hours by wet chemistry.

For your free copy, circle No. 42 on Reader Information Card.

Welding Fittings and Flanges

Two technical data cards have just been released by the Tubular Products division of the Babcock & Wilcox Co., 161 E. 42nd St., New York, N. Y. Technical Data Card FDC-251 furnishes approximate weights of the many sizes and types of forged steel flanges, while Technical Data Card FDC-250 supplies the weights of eight different types of welding fittings in a full list of sizes.

For your free copies, circle No. 43 on Reader Information Card.

Spot and Projection Welders

Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill., announces a new bulletin 317-2R, which describes the Sciaky Type SP 2 spot welder and Type EP 2 projection welder.

These air-operated press-type, low-impedance, single-phase welders can reportedly be used for a wide range of high production fabricating applications. The 6-page folder also includes machine data to indicate kva range, throat depths and welding capacities. It also describes optional equipment which extends the range of welder functions.

The Type EP 2 projection welder can be converted as a combination projection-spot welder by using simple tooling supplied as optional equipment.

For your free copy, circle No. 44 on Reader Information Card.

Heat Treating

Ferrotherm Co., 1861 E. 65th St., Cleveland, Ohio, offers a new technical "Datalog" on heat-treating processes and processing equipment. This 7-page folder covers protective atmosphere annealing, brazing and hardening of a wide variety of metals, including stainless steel, in continuous, batch or pit-type furnaces.

For your free copy, circle No. 45 on Reader Information Card.

Metallizing

A brochure covering phases of metallizing has just been published by the Metallizing Co. of Los Angeles, 1233 S. Boyle Ave., Los Angeles 23, Calif.

The illustrated brochure explains the advantages that metallizing, or metal spraying, offers to five separate fields, namely, machine element coatings, corrosion-resistant coatings, heat-resistant coatings, as well as decorative and replica coatings.

For your free copy, circle No. 46 on Reader Information Card.

Circle No. 47 on Reader Information Card →

CONCRETE MIXER MAKER FINDS ARCAIR CUTS COSTS

Finishing operations on rugged, cast "Ni-Hard" blades for batch concrete mixers was slow and costly for the Besser Co. of Alpena, Michigan—builders of concrete block-making machinery.

But the fast, versatile Arcair process solved the problem of removing riser stubs efficiently. Now in 15-20 minutes per stub, the Arcair torch does a job that once took 2 hours of tedious grinding. Savings in time amount to more than 85%, and consumption of grinding wheels has been cut by 75%.

Arcair can help you too! Basic simplicity—electric arc plus ordinary compressed air — makes the patented Arcair torch, with Arcair Copperclad electrodes, the new, efficient, cost-cutting answer to most metal removing problems.

See proof of performance from many industries. Write TODAY for FREE BROCHURE!

Arcair Metal Removal Torches

431 S. Mt. Pleasant St., Lancaster, Ohio

For more details, circle No. 40 on Reader Information Card

for hard surfacing...

McKAY

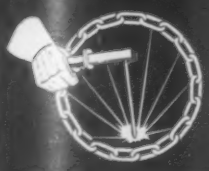
AUTOMATIC & SEMI-AUTOMATIC

tube-alloy® wires

- smooth operation
- high deposition
- uniform, wear-resistant deposits
- controlled chemistry
- wide range of analyses

Years of research, development and experience in welding electrode manufacturing are combined to make McKay "Tube-Alloy" the most efficient and economical wires for automatic and semi-automatic hard surfacing applications. Tube-Alloy wires lay down sound, clean weld deposits of controlled composition and hardness. The closely compacted tubular wires feed smoothly and evenly. Deposition rates are double or more over manual operation . . . thus greatly reducing overall hard surfacing costs.

write for
HARD SURFACING CATALOG



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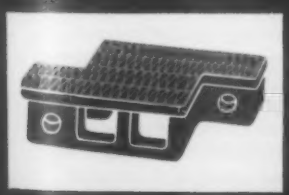
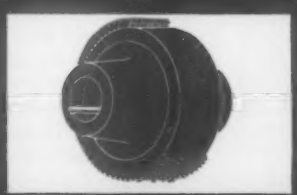
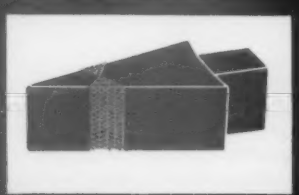


Tractor Rails
TUBE-ALLOY BU WIRE

Ditcher Rollers
TUBE-ALLOY 252



Shovel Rollers
TUBE-ALLOY 258

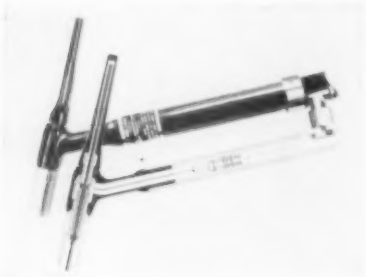


Shovel Bucket Teeth
TUBE-ALLOY 218

NEW PRODUCTS

Inert-Gas Welding Torch

Linde Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y., has announced a new Heliarc hand-welding torch, the HW-18. As described by Linde, an important feature of the new torch is that the cooling water passages are molded in the torch head, giving complete freedom from leakage. Lighter, smaller and more rugged, the torch body is made of Fiberglas-reinforced phenolic with exceptional heat re-



sistance. New gas cups for the torch have improved thermal shock and heat resistance, with impact strength four times greater than usual ceramic cups. For exceptionally hard use, metal sleeved cups are available.

The new torch weighs 7 oz. Improved design of collet bodies gives more efficient argon shielding, thereby conserving gas. Optional shut-off valve on handle also conserves gas, besides saving steps and increasing efficiency.

For more details, circle No. 48 on Reader Information Card.

Nickel Electrodes

Two new welding products have been announced by the International Nickel Co., Inc., 67 Wall St., New York 5, N. Y. One, Inco-Weld "A" wire, is designed especially to give predictable, high-quality automatic and manual inert-gas welds in 95% of the dissimilar metal combinations industry encounters. The other, Inco-Hard "1," is an electrode for hard surfacing steel or cast-iron equipment subject to heavy wear and abrasion.

Inco-Weld "A" wire is said to add greater versatility to the inert-gas welding field, with applications in petroleum refineries, industrial chemical plants, processing plants and nuclear power plants.

Inco-Weld "A" wire reportedly introduces such advantages as a high-strength, corrosion-resistant deposit; machinability; high impact resistance for subzero applications; good elevated temperature properties and X-ray quality welds.

The second new product, Inco-Hard "1," is a metal-arc welding electrode for applying a hard protective surface to low-alloy steels or cast irons which are subject to severe abrasive conditions. The protective overlay is structurally similar to Ni-Hard nickel-chromium alloy, and is intended to give eqiupment prolonged life.

For more details, circle No. 49 on Reader Information Card.

X-Ray Film

A new industrial X-ray film, which has approximately 50% more speed than the fastest Kodak industrial X-ray film presently available, has been announced by Eastman Kodak Co.

Named Kodak Industrial X-ray Film, Type KK, the new film will replace Kodak Industrial X-ray Film, Type K.

It is expected that the new film will prove particularly valuable in cutting exposure time in radiographic inspection of thick sections such as marine propellors or large steel castings.

Despite the increased speed of Type KK Film, tests indicate that in examination for gross defects the film's radiographic sensitivity compares favorably with Kodak Industrial X-ray Film, Type K.

For more details, circle No. 50 on Reader Information Card.

Soldering Alloy

StainTin (R) 157-PA, a solder-type alloy in paint-on paste form for stainless steels has been developed by the Eutectic Welding Alloys Corp., 40–40 172nd St., Flushing, N. Y.

The StainTin 157-PA alloy is finely powdered and silver-bearing, suspended in a balanced liquid-flux composition. The operator paints the paste on the surface, and applies heat, preferably indirect, until the alloy flows and bonds at approximately 450° F.

Other uses for thin-flowing StainTin 157-PA include sealing spot-welded and wrapped seams, step soldering complex assemblies, and filling holes, pits, depressions, tool marks and scribed lines.

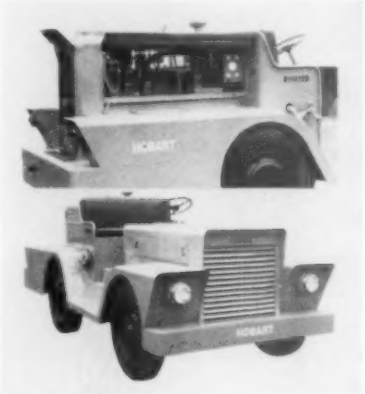
StainTin 157-PA, in addition to stainless steel, can also be used with steels, copper alloys and nickel alloys.

For more details, circle No. 51 on Reader Information Card.

Welder-Compressor

A new self-propelled unit for operations requiring both arc welding current and compressed air has been developed by Hobart Brothers, Co., Troy, Ohio.

Mounted on the rear is a 125 cu ft rotary-type compressor driven by a 4-cylinder gasoline engine. The compressor is completely self-contained with the exception that it draws its gasoline from a common fuel tank.



The welder is a 600-amp d-c unit driven by a Chrysler V-8 engine. This same engine drives the vehicle through a special axle built by Hobart and through a Chrysler Powerflite transmission and torque converter. The unit is also equipped with hydraulic power steering.

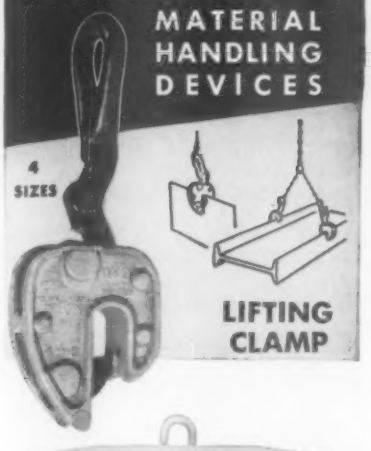
For more details, circle No. 52 on Reader Information Card.

Hard-Surfacing Powder

A nickel-base hard-surfacing powder containing tungsten carbide and chromium borides is now available from Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich. Named Colmonoy No. 75, the new powder is recommended for use with the "Sprayweld" process in applications requiring exceptional resistance to abrasion or to combined abrasion and galling.

The tungsten-carbide inclusion in the new material makes it especially well

YOUR BEST MOVE... MOVE
with **MERRILL**
MATERIAL HANDLING DEVICES



For Interesting Information write

MERRILL BROTHERS

56-33 Arnold Ave., Maspeth, N. Y.

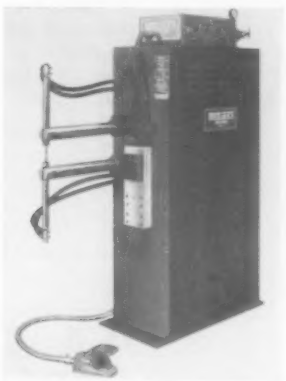
Circle No. 53 on Reader Information Card

suited to applications involving wear caused by scrubbing action or metal-to-metal contact. Since Colmonoy No.75 is suitable for "Sprayweld" application, shape part is no limitation.

For more details, circle No. 54 on Reader Information Card.

Spot Welder

Model SR O, a new single-phase rocker-arm spot welder, has been developed by Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill.



For general purpose applications where relatively light gage metals are fabricated, the unit's control is transistionized with plastic-coated printed circuitry and plug-in components. Welders are available in standard "O" size frame with 30- or 50-kva transformer. Throat depth can be varied by a choice of 6 arm lengths, ranging from 12 to 42 in.

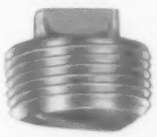
For more details, circle No. 55 on Reader Information Card.

Welding Positioner

Aronson Machine Co., Arcarde, N. Y., has introduced a new line of "unit-frame" turning rolls, designed for load capacities up to 20,000 lb and to handle cylindrical vessels from 3 in. to 6 ft in diam with lengths up to 20 ft. Various sizes of rubber and steel tires are featured with "taper-lock" hub bushings.

For more details, circle No. 56 on Reader Information Card.

New
TAPPING TEE
FOR GAS MAINS
by Nibco



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Circle No. 57 on Reader Information Card

Welding and Cutting Outfit

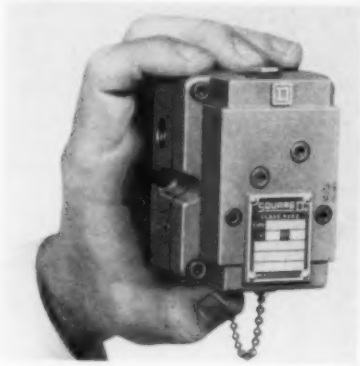
Smith Welding Equipment Corp., 2633 S. E. 4th St., Minneapolis, Minn., has introduced a package outfit for oxyacetylene welding and cutting suitable for such applications as welding, burning, heating, brazing and soldering. Included in the carton are a standard

torch handle, 3 welding tips, cutting assembly, 1 cutting tip, oxygen regulator, pre-set acetylene regulator, goggles, torch lighter and hose. Called the "Big 98," the outfit includes such features as the elimination of torch wrenches and the reported elimination of backfires by the "Flo-trol" system of gas control.

For more details, circle No. 58 on Reader Information Card.

Air Valve

A new 4-way air valve for use with spot welders, pneumatic tools and other industrial applications, has been announced by Square D. Co., Milwaukee, Wis. The use of a rotary magnet simplifies design, permits mounting in any



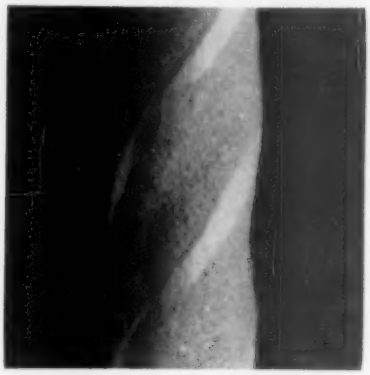
position. Because of its small size, the new valve can be mounted at the cylinder, eliminating the need for long air lines between valve and cylinder.

Balanced internal pressure helps increase service life; the new Square D air valve has been tested at more than 25 million operations. Change of direction in the air flow takes place in less than $\frac{1}{2}$ cycle at 60-cycle frequency. Full $\frac{1}{4}$ in. porting is provided throughout the unit.

For more details, circle No. 59 on Reader Information Card.

Continuous Filler Wire

Announcement of a new continuous-arc mild-steel welding system has just been made by Canadian Liquid Air Co. Ltd., Montreal, Canada.



The new process will be known as the Dynaweld system. According to Liquid Air, this system is completely independent of water cooling or gas shielding.

The Dynaweld system is comprised of a precision-twisted coated filler wire. The wire is drawn off its power-driven supply reel at predetermined speeds through associated equipment and fed through a specially designed pistol-type electrode holder. Welding current is supplied from any standard a-c or d-c welder, the latter being preferred.

For more details, circle No. 60 on Reader Information Card.

Aluminum Bronze

Victory over a prime metallurgical problem—stress corrosion cracking—is claimed by Ampco Metal, Inc., 1745 S. 38th St., Milwaukee, Wis., producer of aluminum bronzes, as a result of conclusive field testing of its new Ampco Grade 8 alloy.

The alloy has been successfully patented in the U. S., and additional patents are pending in six foreign countries.

J. D. Zaiser, president of Ampco, predicted the company's discovery will provide great impetus to the use of aluminum bronze in competition with nickel-bearing and stainless-steel alloys in many applications which have heretofore been confined to these alloys.

For more details circle No. 61 on Reader Information Card.

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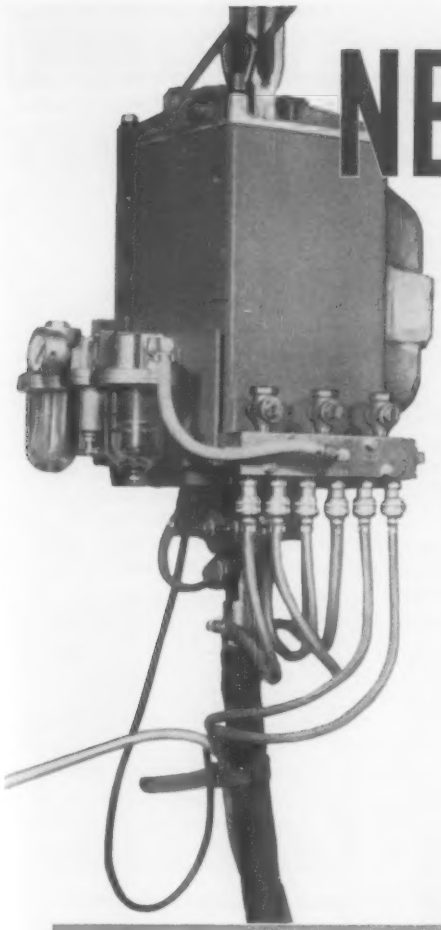
24 COMMERCE STREET, NEWARK, N. J.

For more details, circle No. 62 on Reader Information Card

NEW GUN HANDLE AIR VALVE SAVES UP TO 80% OF AIR!



✓ Eliminates one of the two hoses normally needed between valve and cylinder!

✓ Saves all of the air previously lost in filling and exhausting the two hoses!

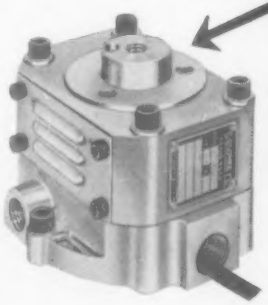
SMALL AND LIGHT... doesn't get in operator's way or give him a lot of extra weight to handle.

HIGH SPEED because line air pressure is always available at the gun.

LOW NOISE LEVEL because built-in muffler virtually eliminates exhaust noise—reduces operator fatigue.

LONG LIFE for valve because there's only one moving part and it "floats on air," eliminating friction wear. Long life for cylinder, too, because air exhaust at gun cools cylinder and increases operating efficiency. Performance-tested by more than *25 million* operations on welding gun.

SIMPLE MAINTENANCE... plug-in valve head can be changed without removing electrical connections or air piping.



Write for Bulletin SM-276
Address Square D Company, 4041 North Richards Street, Milwaukee 12, Wisconsin

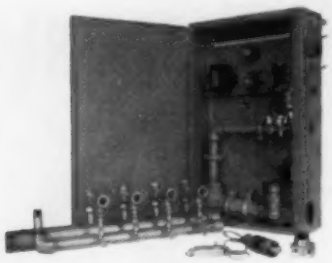
EC&M HEAVY INDUSTRY ELECTRICAL EQUIPMENT... NOW A PART OF THE SQUARE D LINE

SQUARE D COMPANY

For more details, circle No. 63 on Reader Information Card

Water Mizer

Van Vooren Products, 2133 9th St., East Moline, Ill., have introduced a new model "water mizer" for application where "Hi-Lo" outlet ports are removed from the main control unit, such



as on large projection welders, multi-gun multi-transformer welders and air compressors. According to the manufacturer, this new SP series can be furnished with as many "Hi-Lo" ports as needed for the application. Each port can reportedly be adjusted for the required water flow.

For more details, circle No. 64 on Reader Information Card.

Soldering Flux

Anchor Metal Co., Inc., 966 Meeker Ave., Brooklyn 22, N. Y., has developed an organic base flux that is claimed to be highly active yet completely noncorrosive.

This flux, designated as Anchor No. 302, strips oxides from stainless steel, steel, nickel and nickel-chromium alloys, simplifying soldering of these metals. This high activity is achieved without using zinc or ammonium chlorides, acids or rosin. The flux reportedly has an exclusive organic base that will not attack metal in either its original form or in the residue.

For more details, circle No. 66 on Reader Information Card.

Anti-Spatter Compound

"Weld-Gard," a special chemical compound which prevents the adhesion of weld spatter to the surrounding metal surface, is available from Clarkson Laboratories, Inc., 930 N. Darien St., Philadelphia 23, Pa. A viscous amber liquid with a mild, pleasant odor, the compound is reportedly nontoxic, noninflammable and noncorrosive to both ferrous and nonferrous metals.

"Weld-Gard" is applied to the metal adjacent to surfaces to be welded by a brush or rag. Once applied, it forms a tough barrier which prevents molten weld spatter from adhering to the metal. The "Weld-Gard" and spattered metal is removed by washing off with water or by wiping with a wet sponge or rag.

For more details, circle No. 67 on Reader Information Card.

Turntable Positioner

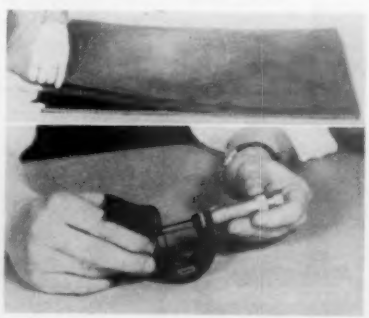
Designed by Aronson Machine Co., Arcade, N. Y., for use with materials subjected to drilling and tapping operations, the FT75CS turntable positioner has a load capacity of 75,000 lb, center of gravity location within 12 in. of center of table. Table rotation with 35,000 lb in. of torque at 2.5 rpm constant speed is provided by a 2-hp brake-motor. The 72-in. diam 8-slot table $2\frac{1}{2}$ in. thick has 1-deg increment marks at periphery with an indicator to establish degree of

rotation. A powered horizontal base of heavy-duty construction mounted on 4 Vee-groove self-cleaning machined steel wheels allows 3 ft forward and reverse movement of the positioner. The movable base is powered by a $\frac{3}{4}$-hp gear motor and is equipped with a cam-lock handle to secure positioner on tract during setup and drilling operations. The control station is on 110-v safety control circuit with 20-ft remote control 4-button station.

For more details, circle No. 68 on Reader Information Card.

Honeycomb Brazing Sheet

A new Nicrobraz honeycomb brazing sheet 0.005 or 0.010 in. thick for use with stainless steels, high alloys and ti-



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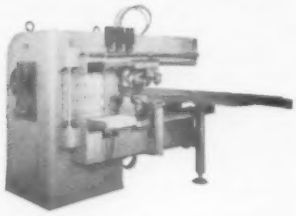
PRECISION to manufacture foil welding machines



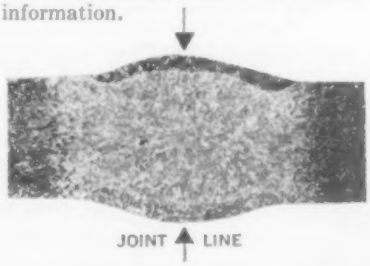
Exclusive licensee in U. S. and Canada
for Peco Foil Butt Seam Welding under U. S. Patent No. 2,812,417

The Peco Foil Butt Seam Welding Process has been used in European production with outstanding success. Now, here in America, Precision is manufacturing machines using this patented process, as exclusive licensee in the United States and Canada.

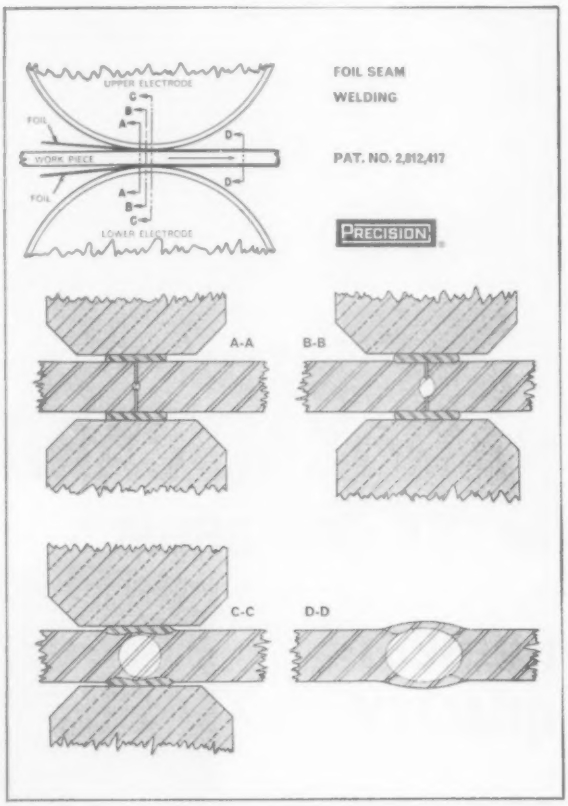
With these new Precision machines, you can make smooth, non-overlapping seam welds of dense structure and high strength—at higher speeds than ever before. Welds have been made on .078″ stock at 3 to 24 feet per minute. Because the Peco process requires less heat and pressure than mash welding there is less power demand and less warping of sheets. Can be used for mild steel, low alloy, high carbon and stainless steel.

Typical applications include: railroad car industry (welding sides and roofs), automotive industry (welding fenders, mufflers and gasoline tanks), appliance industry (welding washing machine tubs, dishwashers, sinks and refrigerators), steel mill industry (joining ends of coils), welding dairy containers and various applications in aircraft and other industries (often in place of seam, flash or fusion welding).

The new Precision Foil Welding Machines are the latest development in our continuing program to advance resistance welding techniques. Other Precision developments include Magnetic Force Welding, Magna-Flash Welding, Vinyl Coated Steel Welding, and machine tool construction with the Ball Bearing Ram. Call or write today for complete information.



Photomacrograph—.078″ mild steel, foil butt seam welded at 144″ per minute.



Foil acts as a bridge to distribute welding current to both sheets, and also prevents too-rapid withdrawal of heat from the joint area. Foil strip offers added electrical resistance and helps contain the molten weld nugget while it grows in area and cools. Sheets are generally clamped, and in some instances the foil is spot tack welded at lower heat before being seam welded.

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Builders of all types Resistance Welders and High-Speed Presses
Manufacturing Plants in United States and Canada

For more details, circle No. 69 on Reader Information Card

tanium is now available from Stainless Processing Division of Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

Development of the thin, flexible sheet represents more than two years of investigation in Wall Colmonoy's research laboratories. The new sheet thicknesses are recommended for application in the manufacture of brazed honeycomb structures for high-temperature service. Being flexible, the new material adapts readily to contoured surfaces.

For more details, circle No. 70 on Reader Information Card.

Resistance-Welding Holders

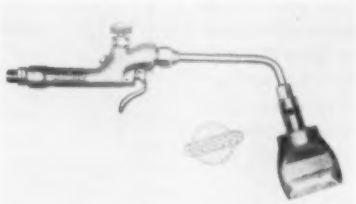
A new line of standardized resistance-welding holders has been announced by P. R. Mallory & Co. Inc., Indianapolis 6, Ind. More than one thousand separate combinations of resistance-welding setups are now possible with such interchangeable components as holders, barrels and adaptors. Many of these combinations, according to the manufacturer, could be accomplished previously only by specially designed holders.

The versatility of the new Mallory welding holder line reportedly offers a number of advantages to manufacturers who use resistance welding.

For more details, circle No. 71 on Reader Information Card.

Paint Burner

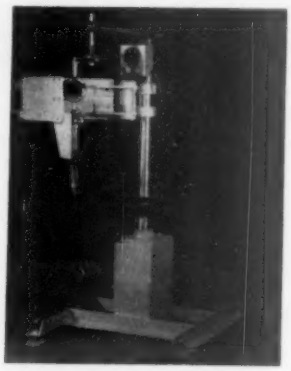
Weldit, Inc., 990 Oakman Blvd., Detroit 38, Mich., has developed a new paint burner that gives a wide, flat, ribbonlike flame. With the Weldit air control, the flame can be adjusted from hard to soft and from short to long. The 486 paint burner is made to fit three standard Weldit torches, the C-48P with automatic trigger control, the C-48WP and the B-56P.



For more details, circle No. 73 on Reader Information Card.

Cutting Machine

Speedi-Burn Products Co., 534 Linden St., West Hempstead, N. Y., has introduced a flame-cutting machine for cutting irregular shapes from steel plate. According to the manufacturer, the unit is used principally for cutting thickness within the range of 1/4 to 2 in. with respective cutting rates of 24 and 10 ipm. A variable-speed gear-head motor is used to drive the tracing head.



For more details, circle No. 74 on Reader Information Card.

X-Ray Unit

Picker X-Ray Corp., 25 S. Broadway, White Plains, N. Y., has introduced an X-ray unit known as the Picker Cyclops Cobalt 60 for radiographic inspection of steel castings, weldments and other steel products. According to Picker, determinations can be made on steel products up to 10 in. thick in a reasonable period of time with 1 and 2% radiographic sensitivity. The manufacturer points out that this particular unit is adaptable for smaller companies in need of X-ray equipment. The Picker Cyclops will reportedly radiate energy

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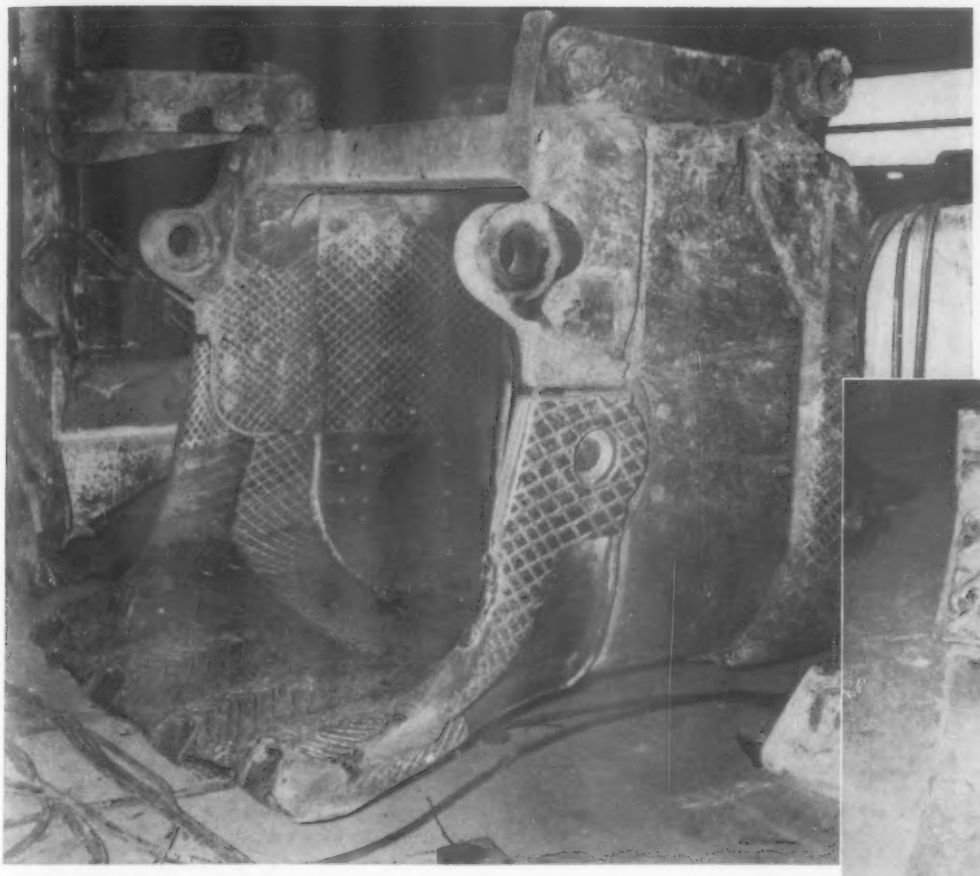

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Better wear protection, faster application on shovel parts with STOODY SEMI-AUTOMATIC HARD-FACING!

Hard-facing jobs that used to take hours can now be done in minutes. These tremendous time-savings are the result of Stoody Semi-Automatic Hard-Facing...a process that puts down 2 to 4 times more hard metal per hour than is possible by manual welding. Here's a way not only to cut maintenance costs, but to simultaneously lighten work loads on welding crews...provide more time to finish work that normally piles up—or never gets done!

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TEST STOODY SEMI-AUTOMATIC HARD-FACING IN YOUR OWN PLANT—Arrange now for a personal demonstration with any Stoody Distributor. Check the Yellow Pages of your phone book or write direct.

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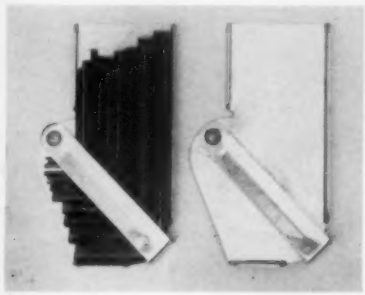
equivalent to the 2 to 3 million volt X-rays needed to penetrate many of the components used in the construction of nuclear reactors.

For more details, circle No. 76 on Reader Information Card.

Allen Wrench Holder

Contour Marker Corp. of Compton, Calif., announces the production of their new "Co-Ma-Co" Allen wrench holder.



This carrier holds 10 or more Allen wrenches of various sizes for quick and easy selection.

The holder clamp is slipped off-center for quick removal or replacement of any size Allen wrench.

For more details, circle No. 77 on Reader Information Card.

Heat Treating

Airline Welding and Engineering Corp., 750 N. Prairie Ave., Hawthorne, Calif., has announced the development of interchangeable temperature-controlled mandrels for pre- and postweld heating of crack-sensitive metals for the company's LW 10000 Series longitudinal and C-20000 Series circumferential welding machines.

The new system features thermostatically controlled, electrical immersion, remote heating unit in which special oils may be heated from 80 to 600° F with a variation of only 15° F. The oil is circulated, under pressure, through the welding backing mandrel and returned for reheating. Heat from the oil is transferred, by conduction, to the steel mandrel and copper or steel backing bar.

For more details, circle No. 78 on Reader Information Card.

Semiautomatic Welder

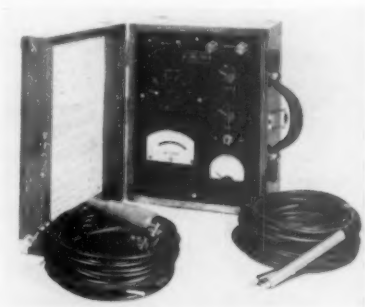
A new portable welding machine for semiautomatic application of hard-surfacing wire is now available from Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

Designated the Colmonoy semiautomatic welder, the new machine features a 14-ft flexible shaft for greater working range from one position, and a double-range arc-length control circuit for greater operating range and better welding control. For simplified maintenance and service, plug-in circuit construction is utilized. The welder operates from any welding machine 300 amp or larger. Power source may be a-c, d-c rectifier, motor-generator, gas drive or constant potential machine. No alterations are required when switching from ac to dc.

For more details, circle No. 79 on Reader Information Card.

Weld Preparation for Aluminum

J. W. Dice Co., Englewood, N. J., manufacturers of nondestructive and physical test instruments, has introduced the "microhm meter," a surface resistance tester, to determine the cleanliness of aluminum or other sheet material prior to spot welding. The meter measures the resistance of coupons in a test jig or the resistance of actual sheets at the welder head.



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Use Pureco CO_2 for LOW COST gas shielded metal arc welding

Pureco carbon dioxide, used as a gas shield by fabricators of mild steel, will provide quality welds with unusual economy.

Carbon dioxide is ideal for both single and multi-pass applications, manual or automatic, with large or small diameter wires. And now—you can also use CO_2 for *position* manual welding.

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15	40	65	90	115	140
16	41	66	91	116	141
17	42	67	92	117	142
18	43	68	93	118	143
19	44	69	94	119	144
20	45	70	95	120	145
21	46	71	96	121	146
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ELECTRODE-TIP LIFE STUDIES IN SERIES SPOT WELDING

Study includes the effects of electrode geometry, electrode material, electrode force and welding current on weld strength, weld diameter, weld consistency and electrode life

BY E. F. NIPPES, W. F. SAVAGE, S. M. ROBELOTTO AND K. E. DORSCHU

ABSTRACT. The effects of electrode geometry, electrode material, electrode force and welding current on weld strength, weld diameter, weld consistency and electrode life were investigated for series spot welds in as-received auto-body stock. As a result of this study, an optimum combination of welding variables was determined for series spot welding pickled-and-lightly-oiled auto-body stock.

A study of the effect of electrode geometry on weld consistency indicated that a 2-in. continuous-radius domed electrode provided more consistent welds than the $^5/_{16}$-in. continuous-radius dome often used in commercial practice. An additional study demonstrated that welding conditions which did not produce flashing at the electrodes provided more consistent welds than welding conditions which caused flashing.

Introduction

The many advantages of series spot welding have resulted in wide application of the process to the fabrication of mild-steel sheet. In a previous investigation conducted at Rensselaer Polytechnic Institute,[1] the satisfactory spot-welding conditions were determined for degreased and for degreased-and-pickled steel auto-body stock. However, since industrial practice often requires welding the pickled-and-oiled auto-body stock in the as-received condition, the results of the above investigation could not be directly translated into industrial practice.

Although welding auto-body stock in the as-received condition has both advantages and disadvantages, the advantages generally outweigh the disadvantages in commercial production. If the steel were degreased and repickled prior to fabrication, then usually an additional operation would be required to remove the oxides from the finished product before paint was applied. On the other hand, two major disadvantages result from welding auto-body stock in the as-received condition: (1) decreased electrode life; (2) porosity in the weld zone. The decrease in electrode life results from flashing at the electrode-to-work interface due to the high, inconsistent, surface-contact resistance of the as-received stock. Porosity is caused by the entrapment of the gases formed by the decomposition of the protective oil in the weld zone and may result in a significant decrease in weld strength. In a previous report,[1] satisfactory conditions for series spot welding 0.036-in. stock in the degreased-and-pickled condition were reported to be:

Electrode material:	RWMA Class 2
Electrode Geometry:	$^5/_8$ in. over-all diam with $^7/_{32}$ in. restricted diam dressed to 6 in. radius
Electrode force:	360–400 lb
Welding current:	10,000–11,500 amp
Welding time:	12 cycles
Electrode spacing:	2 in.

However, the above welding conditions caused flashing after 140 welds and resulted in undesirably short electrode life when employed with as-received stock. It was therefore evident that further evaluation of welding conditions was required to determine the optimum welding conditions for long electrode life for as-received, pickled-and-oiled stock.

It is generally recognized that flashing at the electrodes will not occur during spot welding if optimum procedures are used. However, in production the maintenance of optimum procedures often must be compromised and flashing at the electrodes is frequently encountered. Although the effect of flashing on the consistency of welds has been the subject of considerable controversy, comparative data are not available.

Another complication arising in commercial production stems from the complexity of shapes encountered in commercial joining operations. In cases where considerable misalignment between the electrode and the work is unavoidable, practice dictates the use of electrodes dressed to a small, continuous-radius dome. An electrode geometry frequently employed in automotive production involves a $^5/_{16}$-in. radius dome. With a dome of such small radius,

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flashing at the electrode-work interface usually results when sufficient welding current is used to produce the desired weld diameter in 0.036-in. auto-body steel.

Object

The present investigation had two major objectives:

1. To determine the optimum welding conditions for welding as-received, pickled-and-lightly-oiled auto-body stock.
2. To compare the consistency of welds made under conditions which produced flashing at the electrode-work interface with the consistency of welds made under conditions producing no flashing at the electrodes.

Material

Cold-rolled, rimmed steel supplied in the pickled-and-lightly-oiled condition was employed throughout this investigation. Three lots of steel were used of thickness 0.036, 0.038 and 0.039 in.; the chemical analyses of the 0.036- and 0.039-in. materials are given in Table 1, as are the mechanical properties of the three thicknesses.

Table 1—Chemical Analyses and Mechanical Properties of Material Used

	—Chemical analyses, %—	
Element, %	*0.036-in. material*	*0.039-in. material*
Carbon	0.055	0.065
Manganese	0.33	0.29
Silicon	0.01	...
Phosphorus	0.010	0.008
Sulfur	0.035	0.032
Copper	0.09	...
Nickel	0.05	...
Chromium	0.01	...
Molybdenum	0.01	...

	—Mechanical Properties— Stock thickness, in.		
	0.036	*0.038*	*0.039*
Tensile strength, psi	47,800	44,800	47,600
Yield strength (0.2%), psi	37,200	30,900	34,800
Elongation (%) in 2 in.	36.2	39.5	38.0
Surface contact resistance	700–1500 microhms		

Since all lots were received from the producer in the pickled-and-lightly-oiled condition, this is hereafter referred to as the as-received condition.

Equipment

The series spot-welding equipment was assembled during a previous investigation.[1] Briefly, the force on each of the two electrodes was provided by a hydraulic cylinder, the two cylinders being connected to a common manifold to insure that each received the same hydraulic pressure. Oil was supplied to the equalizing manifold from an air-hydraulic booster and the oil pressure was controlled by regulation of the air pressure applied to the air-hydraulic booster.

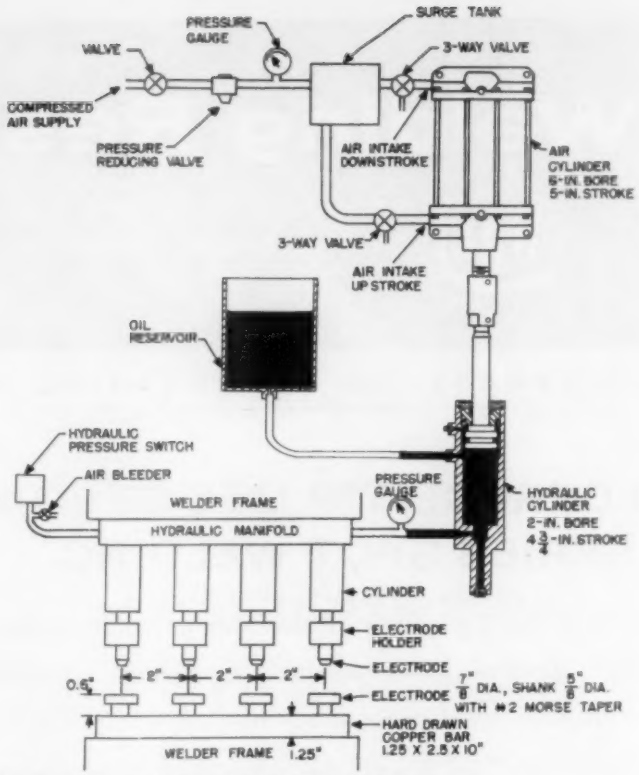


Fig. 1 Schematic of series-welding equipment

Welding current was obtained from a 50-kva Hypersil transformer with 8 taps providing a range of secondary voltages of 4.58 to 6.88 volts when energized with a primary voltage of 440 volts. The transformer employed had two identical secondary windings, but only one secondary was used throughout the present investigation.

RWMA Class 2 or Class 3 electrodes were used in conjunction with a copper backing bar with removable stools, and one side of the secondary winding was connected to each electrode. The details of the hydraulic circuit and the electrode configuration may be seen by inspection of Fig. 1.

The electrodes were internally cooled with water at 65 to 75° F with a flow rate of 1 to 1½ gpm. No difference between inlet and outlet water temperature was noted with the welding procedures utilized in this investigation.

The primary of the welding transformer was energized from a 350-kva single-phase generator, driven by a 125-hp synchronous motor, operating from a 4160-volt, 3-phase, 60-cycle line. The primary welding voltage thus supplied was adjustable over a range from 250 to 550 volts. The weld time was controlled by a synchronous electronic weld timer, and the initiation of welding current flow was adjusted to provide a current wave form as nearly sinusoidal as possible (100% heat).

The welding current, I, was measured using an ampere-squared-second (I^2t) meter, supplied from a current transformer connected in the primary circuit of the welding transformer. The welding time, t, was recorded with a direct-inking oscillograph connected to a current transformer in the welder primary circuit.

Changes in electrode contour during

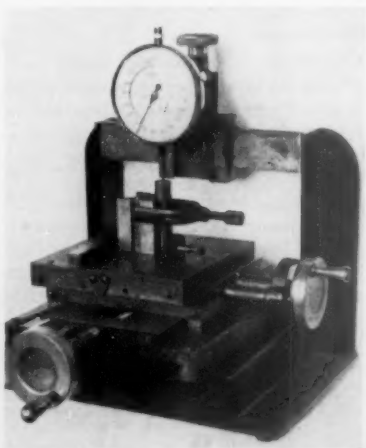
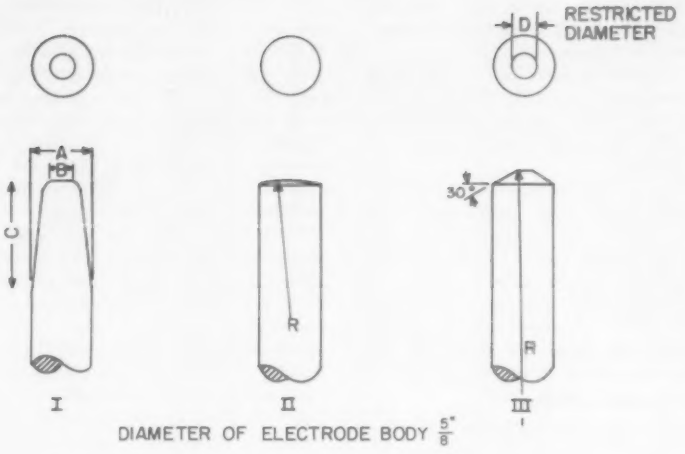


Fig. 2 Photograph of profilometer



I. STANDARD POINTED TIP (A = TAPER-0.625", B = 1/4", C = 1 1/8")

II. CONTINUOUS RADIUS TIPS (R = 5/16, 1 1/2, 2 AND 3")

III. RESTRICTED DIAMETER WITH RADIUS DOME TIPS (D = 7/32", 1/4" WITH R = 6" AND D = 1/4" WITH FLAT ELECTRODE FACE)

Fig. 3 Details of electrode geometries investigated

Table 2—Summary of the Welding Conditions Studied

Material: 0.036- to 0.039-in., cold-rolled rimmed steel, as-received (pickled and lightly oiled)
Welding time: 12 cycles
Weld spacing: 2 in. (center to center)
Backing conditions: Copper backing with Class 2 stools

Life test no.	*Elect. class RWMA*	*—Electrode geometry— Restricted diam, in.*	*Radius of dome, in.*	*Electrode force, lb*	*Welding current, amp*
1	2	7/32	6	380	11,000
2	2	7/32	6	500	11,000
3	2	7/32	6	600	11,000
4	2	7/32	6	600	12,500
5	3	7/32	6	600	12,500
6	2	1/4	6	600	13,500
7	2	1/4	Flat face	600	13,500
8	2	1/4	Flat face*	600	14,000
9	2	Continuous radius	5/16	650	13,200, 16,100 after 200 welds
10	2	Continuous radius	5/16	500	13,300, 16,500† after 1100 welds
11	2	Continuous radius	5/16	350	16,000, 16,500† after 900 welds
12	2	Continuous radius	1.5	700	15,000
13	2	Continuous radius	3	700	15,000
14	2	Continuous radius	2	700	15,000
15	2	Continuous radius	2	700	16,000
16	2	Continuous radius	2	600	15,000
17	3	Continuous radius	2	700	16,000

* This electrode had the standard pointed electrode geometry shown in Fig. 3-I whereas all electrodes with a restricted diameter were of the truncated 30-deg cone type shown in Fig. 3-III.

† The maximum available current was limited to 16,500 amp by the transformer and secondary-circuit design.

welding were measured with a profilometer, the constructional details of which may be seen by reference to Fig. 2. Briefly, the electrode under study was mounted vertically on a compound micrometer stage with 0.001-in. calibrations. A dial indicator with 0.0001-in. calibrations, mounted on a steel frame above the micrometer stage, was equipped with a needle point and was employed to read the vertical height of the electrode surface. The heights of the electrodes at 0.001-in. increments along two mutually perpendicular diameters were read and recorded in order to describe the electrode contour. In this manner, the change in electrode contour produced by a given number of welds could be ascertained. Electrode geometries used in this investigation are shown in Fig. 3.

Procedure

Determination of Optimum Welding Conditions

In order to establish the optimum conditions for series spot welding as-received auto-body stock, each tentative combination of welding conditions was employed in an electrode-life test. Table 2 summarizes the seventeen combinations of welding conditions studied in determining the optimum welding conditions, each combination being identified by means of a "Life-Test" number. It should be noted that the following variables were maintained constant:

Welding time, 12 cycles
Weld spacing, 2-in. (center to center)
Backing conditions, copper backing with stools

Once a tentative combination of electrode geometry and electrode force was decided upon, a strength-current curve was determined. A value of welding current capable of providing adequate weld strength was then selected from the strength-current curve and employed in an electrode-life study. Throughout each electrode-life study, test specimens were prepared as indicated in Fig. 4 after each 100 welds, and the tensile-shear strength was measured. Whenever a loss in strength of more than 10% was observed, a new strength-current curve was determined and a new value of welding current was selected to provide adequate weld strength for the balance of the life test.

In order to define acceptability during a 2000-weld life test, the following criteria were adopted:

1. The tensile-shear strength must exceed 1000 lb for a single weld.
2. The weld strength must not decrease by more than 10%.
3. The weld diameter must exceed 0.18 in., the minimum value specified by MIL-W-12332 (ORD) for this material.
4. Welds must be porosity-free.

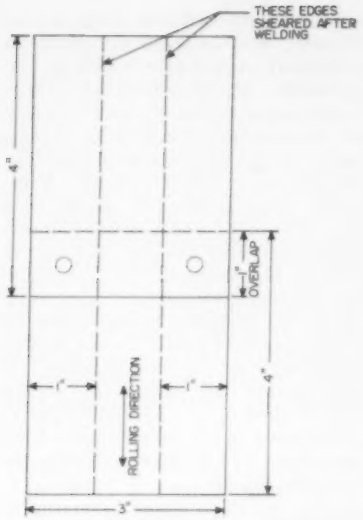


Fig. 4 Tensile-shear test specimen

5. Excessive flashing at the electrode-to-work interface must not occur.

6. The surface appearance of the work must remain satisfactory.

Whenever one or more of the above criteria were no longer satisfied during a particular life test, the test was discontinued, and a new combination of welding variables was selected for study. Although quantitative evaluation of the magnitude of flashing is impossible, qualitative standards were based upon the experience of the operator. In general, whenever the flashing increased markedly as additional welds were made, profilometer measurements indicated that the electrodes were undergoing damage and the life test was discontinued.

The weld diameter was measured by two methods:

1. *Metallographic Method:* The weld specimen was sectioned through the centerline of the fusion zone and the diameter measured using a microscope with a filar eyepiece.

2. *Chisel-Fracture Test:* The weld specimen was fractured by driving a cold-chisel between the sheets and the minimum diameter of the weld measured at the fracture.

When the fusion zone of the weld is regularly shaped, the values of weld diameter measured by the two methods agree reasonably well. However, when the fusion zone is irregular in shape, the value of the weld diameter is usually smaller when measured by the chisel-fracture test, since the minimum diameter is reported in this method.

Weld-Consistency Studies

Table 3 lists the conditions employed in a series of consistency studies. All welds were made in 0.038-in. as-received auto-body stock, using a weld time of 12 cycles, the other variables being as listed in Table 3. The freshly machined electrodes were "conditioned" in each case by making 50 welds prior to preparing the samples for consistency tests.

Since flashing at the electrode-to-work interface usually began after 60 welds with the $^{7}/_{32}$-in. restricted diameters, 6-in. radius domed electrodes, and since the 50-weld "conditioning" practice was used throughout, no more than 10 welds could be obtained with this geometry without flashing. Therefore, 10 welds were taken as a standard sample in all consistency studies involving this electrode geometry. Flashing at the electrode-to-work interface always occurred after 200 welds with the $^{7}/_{32}$-in. restricted diam, 6-in. radius electrodes, and, therefore, weld numbers 201–210 were taken as representative of welds made with flashing for this electrode geometry.

At the request of the advisory committee, a consistency study was performed involving welds made with $^{5}/_{16}$- and 2-in. continuous-radius domed electrodes (Studies' Nos. 3 and 4, Table 3). It should be noted that welds made with 2-in. radius domed electrodes (Consistency Test No. 4, Table 3) were made with less than the optimum current. Rather, the current was adjusted to provide an average weld diameter of as near the 0.18 in. min diam as possible with both electrode geometries.

With each electrode geometry, 50 welds were made with each set of freshly machined electrodes in order to "condition" the electrode surfaces before the test specimens were prepared. The 2-in. continuous-radius electrode exhibited no flashing during welding, while the $^{5}/_{16}$-in. continuous-radius electrode produced heavy flashing at the electrode-to-work interface. Therefore, this comparison may also be considered to be one of the effects of "flashing" vs. "no-flashing."

Normal-tension specimens were prepared and tested as shown in Fig. 5.

Results

In the interest of brevity, only the more significant welding variables have been mentioned in the following discussion of the results of the seventeen life tests. The welding variables have been tabulated previously in Table 2, however, and the reader may wish to refer to this table for a complete description of the welding variables employed.

Determination of Optimum Welding Conditions

Since satisfactory welding conditions for degreased-and-pickled auto-body stock had been previously determined,[1] these conditions were chosen as a starting point for the present study. Electrode Life Test No. 1 was made with as-received stock using the conditions previously determined for the degreased-and-pickled stock. However, flashing at the electrode-work interface began after 140 welds and became so severe after

Table 3—Conditions Used in Weld-Consistency Studies

Material:	0.038-in. cold-rolled, rimmed steel, as-received (pickled and lightly oiled)
Welding time:	12 cycles
Weld spacing:	2 in. (center to center)
Electrode material:	RWMA Class 2
Backing conditions:	Copper backing with Class 2 stools
Cooling water flow:	$1^{1}/_{2}$ gpm, 65 to 75° F.

Consistency test no.	Electrode geometry: Restricted diam, in.	Electrode geometry: Radius of dome, in.	Electrode force, lb	Welding current, amp	Condition at electrode-work interface
1	$^{7}/_{32}$	6	400	10,770	No flashing*
2	$^{7}/_{32}$	6	400	10,770	Flashing†
3	Continuous radius	$^{5}/_{16}$	500	16,200	Flashing
4	Continuous radius	2	650	13,900	No flashing

* No flashing occurred with the first 10 welds after the electrode-conditioning treatment of 50 welds. Therefore, welds 51–60 were used as "no-flashing" samples.

† After 200 welds, considerable flashing occurred regularly. Therefore, welds 201–210 were used as "flashing" samples.

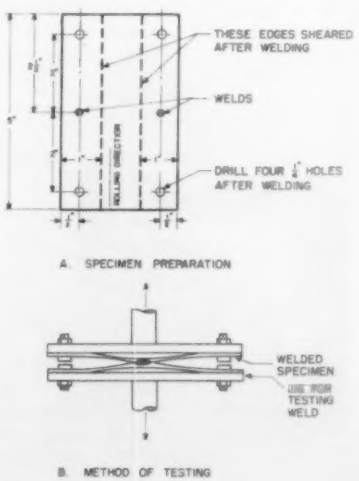


Fig. 5 Normal-tension test

400 welds that the test had to be discontinued.

In an attempt to reduce the flashing, the electrode force was first increased to 500 lb (Life Test No. 2, Table 2) but this test had to be discontinued after 640 welds because of excessive flashing. The electrode force was then further increased to 600 lb (Life Test No. 3, Table 2), but, although the flashing was noticeably reduced, shear failures were prevalent after the first 900 welds, indicating the current of 11,000 amp to be inadequate with the 600-lb electrode force.

After the determination of a strength-current curve for the 600-lb electrode force, a welding current of 12,500 amp was selected and Life Test No. 4 (Table 2) was initiated. With the increased current, considerable flashing was observed throughout the life test, and "mushrooming" of the welding electrodes became serious enough to promote occasional shear failures after 1200 welds had been completed.

In view of the "mushrooming" of the electrode faces noted above, Life Test No. 5 (Table 2) was conducted using the same welding conditions except for the substitution of the harder RWMA Class 3 electrode material for the RWMA Class 2 material employed in all previous tests. Although the flashing at the electrodes was noticeably reduced by this measure, occasional shear failures again were observed after 1600 welds had been completed.

Since it appeared that the current density in the $^{7}/_{32}$-in. reduced-diameter electrode might be excessive with the 600-lb electrode force, it was next decided to explore the use of electrodes with a $^{1}/_{4}$ in. restricted diameter. Life Test No. 6 (Table 2) was therefore conducted using a 600-lb electrode force and RWMA Class 2 electrodes with a 6-in. radius dome on a $^{1}/_{4}$ in. restricted diameter. A welding current of 13,500 amp was selected as satisfactory with the aid of a strength-current curve but occasional shear failures were obtained throughout the life study.

It was noted from profilometer measurements of the electrodes after use (see Fig. 6, representing a typical plot of the electrode contour before and after a life test) that the electrode contour tended to approach that of a flat surface with use. As a result of the above observation, Life Test No. 7 (Table 2) was conducted with the same conditions employed in Life Test No. 6 except that the electrodes were machined with flat faces on the restricted diameters. The resulting welds showed inconsistent strength values, due, in part, to the erratic alignment between the flat electrode surfaces and the work. An additional life test (Life Test No. 8, Table 2) was undertaken, however, using standard pointed electrodes, as shown in Fig. 3-I, with a flat-faced $^{1}/_{4}$ in. restricted diameter. The current during this test was selected with the aid of a strength-current curve as 14,000 amp, but both excessive flashing and inconsistent weld strengths resulted.

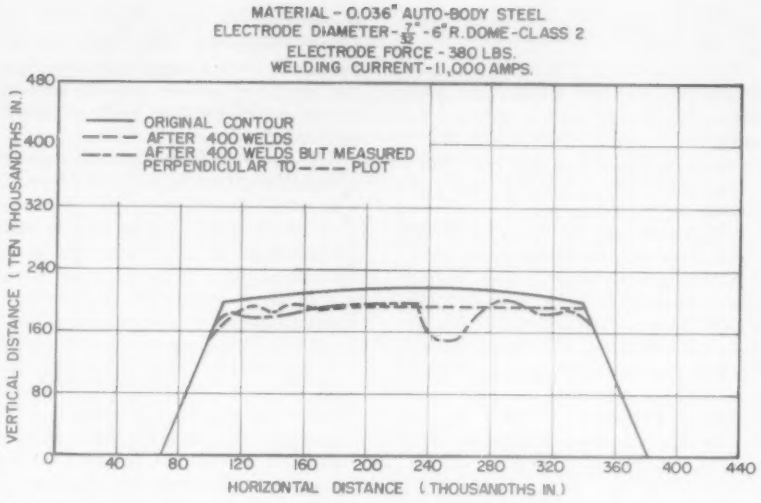


Fig. 6 Change in electrode profile resulting from life study

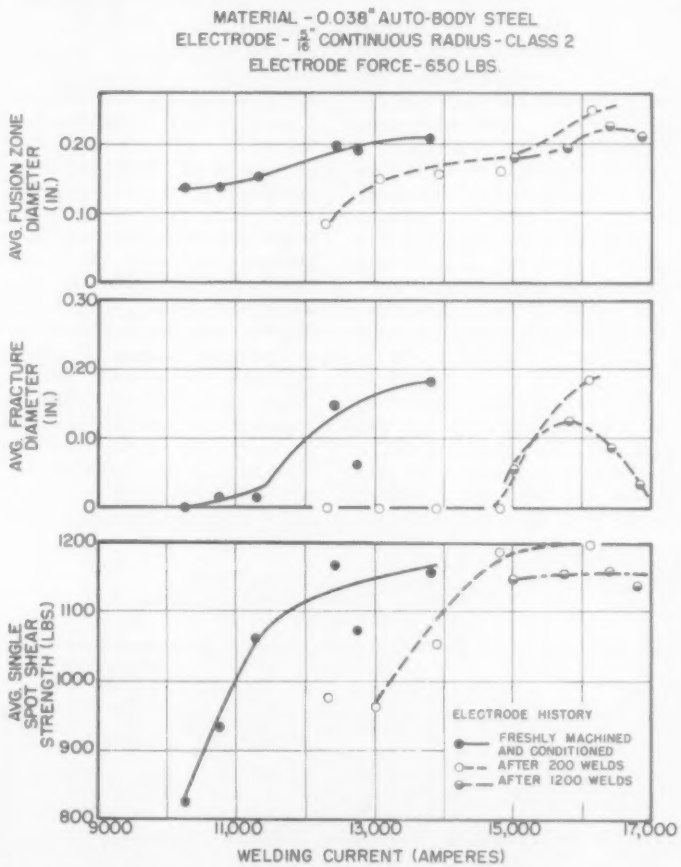


Fig. 7 Strength-weld diameter-current characteristic curves

The results of the first eight life tests summarized above being, in general, unsatisfactory, it was decided to explore the use of electrodes with continuous radius domes. Since the automotive industry often employs a $^{5}/_{8}$-in. diam electrode machined to provide a hemispherical tip ($^{5}/_{16}$-in. continuous radius

dome), this geometry was chosen as a starting point.

Life Test No. 9 (Table 2) was conducted with RWMA Class 2 electrodes with a $^5/_{16}$-in. continuous radius dome using an electrode force of 650 lb. A strength-current curve was run, and a welding current of 13,200 amp was chosen as providing satisfactory weld strength and weld diameter. After 200 welds, however, the weld strength and weld diameter dropped below the acceptable limits and a new strength-current curve had to be run. The results indicated that the current should be increased to 16,100 amp in order to restore the desired weld strength. After a total of 1250 welds, however, the test had to be discontinued since the weld diameter had decreased to 0.12 in., well below the acceptable 0.18-in. value.

Figure 7 shows typical strength-current curves taken with freshly machined electrodes, after 200 welds and after 1200 welds, together with data on weld diameter as a function of weld current after the same intervals. The large variations in weld characteristics are significant indications of the rapid deterioration of the $^5/_{16}$-in. continuous radius domed electrode.

Since the electrodes used in Life Test No. 9 above showed excessive distortion, Life Test No. 10 (Table 2) was initiated with an electrode force of 500 lb and a current, as determined from a new strength-current curve, of 13,300 amp. After 1100 welds, the weld diameter had again decreased to below the acceptable value and the current had to be increased to the maximum attainable value of 16,500 amp for the balance of the life test. Although the strength remained acceptable for the balance of a 2400-weld life test, the weld diameter fell off sharply to below the acceptable value after 2200 welds and occasional shear fractures were observed in the tensile shear tests. Profilometer measurements were taken, indicating that the electrode surface was undergoing excessive deformation even at 500-lb electrode force.

The electrode force was then reduced to 350 lb and Life Test No. 11 (Table 2) was initiated with a current of 16,000 amp. After 900 welds, the weld current was increased to 16,500 amp, the maximum available. Although some sticking occurred at the electrode-to-work interface for the first 400 welds, and considerable flashing occurred throughout the life test, the weld strength and weld diameter remained at acceptable levels for 2400 welds. The shape of the fusion zone was irregular, however, and varied throughout the test as the electrode contour deteriorated. In addition, considerable porosity was found in the welds.

The results of the above tests with $^5/_{16}$-in. continuous radius domed electrodes indicated the desirability of increasing the radius of curvature of the electrode face. Therefore, Life Test No. 12 was conducted using RWMA Class 2 electrodes with a 1.5-in. radius dome and a 700-lb electrode force. The welding current of 15,000 amp was determined with the aid of a strength-current curve. The weld diameter decreased to below the acceptable 0.18-in. value, however, and the occasional shear failures occurred after the first 350 welds. In addition, some flashing was observed and it was therefore decided to investigate continuous radius domed electrodes with somewhat greater radii. A 3-in. continuous radius dome proved unsatisfactory (Life Test No. 13, Table 2) because the electrode face deteriorated to the extent that a "double-spot" weld was produced after 1500 welds.

A 2-in. continuous radius domed electrode proved to be the most satisfactory compromise. Life Test Nos. 14, 15, 16 and 17 were all conducted with this electrode geometry, and all proved acceptable despite the fact that the electrode force was varied from 600 to 700 lb, and the welding current was varied from 15,000 to 16,000 amp. The tensile shear strengths averaged 1400 ± 100 lb and no shear failures were encountered. The weld diameters averaged 0.21 in., well above the 0.18-in. value taken as the minimum acceptable diameter according to MIL-W-12332 (ORD) specifications. Furthermore, no appreciable flashing occurred at any point in the three life tests performed with the 2-in. continuous radius domed RWMA Class 2 electrodes, but some flashing was observed with the harder RWMA Class 3 electrodes (Life Test No. 17, Table 2). No porosity was found in the welds sectioned for metallographic examination when 2-in. continuous radius domed electrodes were used.

As a result of the above electrode life studies, the optimum series spot-welding conditions for as-received, pickled-and-lightly-oiled auto-body stock, 0.036 to 0.039 in. thick, are as follows:

Electrode material:	RWMA Class 2
Electrode geometry:	2-in. radius continuous dome on $^5/_8$-in. diam electrodes.
Electrode force:	650 lb (600 to 700 lb)
Welding time:	12 cycles
Welding current:	15,000 to 16,000 amp
Weld spacing:	2 in. (center to center)

Figure 8 shows both weld strength and weld diameter as a function of weld current for the above conditions. The upper curves are weld diameter as measured by metallographic (open circle) and chisel-fracture tests (solid

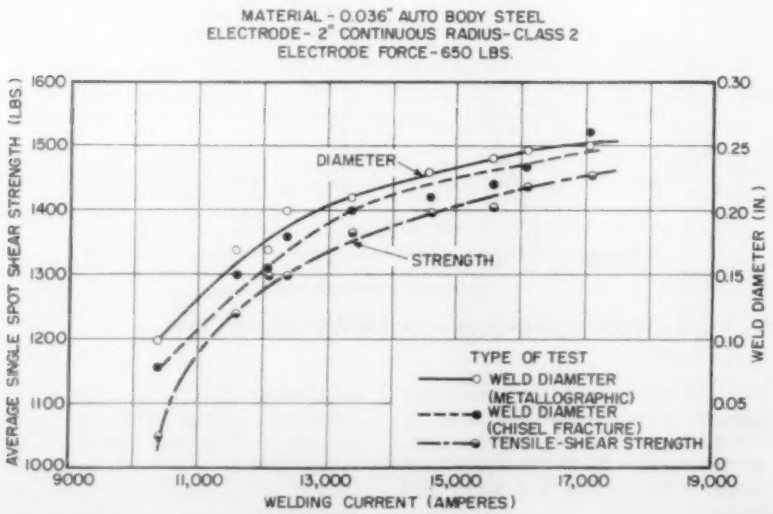


Fig. 8 Strength-weld diameter-current correlation curves

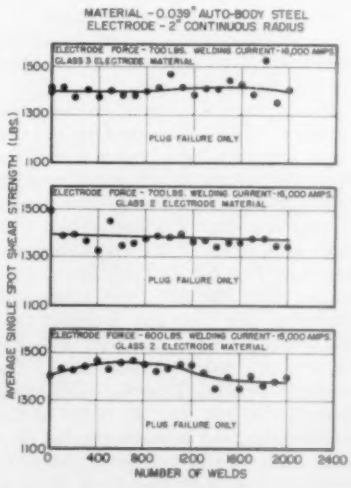

MATERIAL - 0.039" AUTO-BODY STEEL
ELECTRODE - 2" CONTINUOUS RADIUS
PLUS FAILURE ONLY
AVERAGE SINGLE SPOT SHEAR STRENGTH (LBS.)
NUMBER OF WELDS

Fig. 9 Variation in weld strength during electrode-life study

circle). The lower curve is the tensile-shear strength of a single weld as a function of welding current.

Figure 9 summarizes the variation in weld strength during 2000-weld life tests for three combinations of welding conditions in the range of the optimum conditions. The upper curve was obtained using RWMA Class 3 electrode material, the lower two curves with RWMA Class 2 material at electrode forces of 700 and 600 lb, respectively. It is to be noted that the single-spot tensile-shear specimens fractured with a plug (ductile-tear) failure throughout the life tests.

Weld-Consistency Studies

Although it was difficult to avoid flashing with the $^{7}/_{32}$-in. restricted diameter electrode with a dome, 10 welds were obtained by selecting welds number 51–60 of a series. The weld-strength and weld-diameter data for these welds are tabulated in Table 4 in the column headed, "Welds Made Without Flashing."

By the time 200 welds had been made with a set of electrodes of this geometry, the flashing at the electrodes became excessive, and welds 201–210 were taken as representative of this condition. The results of tests of these welds having excessive flashing are tabulated in Table 4 under the heading, "Welds Made with Flashing."

The data in Table 4 (taken from Consistency Studies 1 and 2, Table 3) have been arranged to show the range of values measured; the standard deviation (σ); and the ratio of the standard deviation to the rms value, expressed in percent. It may be seen by inspection of Table 4 that, except for the normal-tension strength, the standard deviation is less for the welds made without flashing. (The normal-tension strength values exhibit a higher standard deviation for the welds made without flashing as a result of the irregular tearing of the parent sheet produced by the higher strength welds obtained when no flashing occurred.) The ratio of the standard deviation to the rms value for weld diameter as measured by the chisel-fracture test is much greater for the welds made with flashing (27.4%) than for welds made without flashing (5.45%).

In general then, the results of Consistency Studies Nos. 1 and 2 (Table 3) indicate that welds made without flashing at the electrode-work interface are more consistent than welds made with flashing. Further examination of Table 4 indicates that the weld strengths are greater, and the weld diameters are larger when no flashing occurs at the electrodes.

Table 5 summarizes the results of Consistency Studies 3 and 4, Table 3. The data shown in the right-hand

Table 4—Comparison of Welds Made With and Without Flashing

Material:	0.038-in. cold-rolled, rimmed steel, as-received (pickled and lightly oiled)
Electrode geometry:	$^{7}/_{32}$-in. restricted diameter with 6-in. radius dome
Electrode material:	RWMA Class 2
Electrode force:	400 lb
Welding time:	12 cycles
Welding current:	10,770 amp
Weld spacing:	2 in. (center to center)
No. of specimens:	10 at each condition

	Welds made without flashing	*Welds made with flashing*
Tensile-shear strength:		
Range of 10 values, lb	1040–1150	920–1050
Rms value, lb	1089	993
Standard deviation, σ, lb	29.5	37.8
σ/rms ratio, %	2.75	3.81
Normal-tension strength:		
Range of 10 values, lb	380–610	180–270
Rms value, lb	433	221
Standard deviation, σ, lb	67.1	28.3
σ/rms ratio, %	15.5	12.8
Weld diameter (chisel-fracture method):		
Range of 10 values, in.	0.13–0.15	0.06–0.14
Rms value, in.	0.142	0.098
Standard deviation, σ, in.	0.008	0.027
σ/rms ratio, %	5.45	27.4
Weld diameter (metallographic method):		
Range of values, in.	0.18–0.21	0.15–0.21
Rms value, in.	0.20	0.18
Standard deviation, σ, in.	0.009	0.019
σ/rms ratio, %	4.3	11.0
Ductility ratio	0.364	0.277

Table 5—Comparison of Welds Made With $^{5}/_{16}$-and 2-In. Continuous Radius Domed Electrodes

Material:	0.038-in. cold-rolled, rimmed steel, as-received (pickled and lightly oiled)
Electrode material:	RWMA Class 2
Welding time:	12 cycles
Weld spacing:	2 in. (center to center)
No. of specimens:	20 at each condition

	2-in. continuous radius electrode, 650-lb force, 13,900 amp	*$^{5}/_{16}$-in. continuous radius electrode, 500-lb force, 16,200 amp*
Tensile-shear strength:		
Range of 20 values, lb	1120–1310	1030–1210
Rms value, lb	1209	1154
Standard deviation, σ, lb	45.1	52.0
σ/rms ratio, %	3.74	4.5
Normal-tension strength:		
Range of 20 values, lb	360–480	200–380
Rms value, lb	439	320
Standard deviation, σ, lb	27.3	40.5
σ/rms ratio, %	6.22	12.65
Weld diameter (chisel-fracture method):		
Range of 20 values, in.	0.15–0.21	0.14–0.20
Rms value, in.	0.182	0.184
Standard deviation, σ, in.	0.012	0.015
σ/rms ratio, %	6.18	7.98
Weld diameter (metallographic method):		
Range of 20 values, in.	0.21–0.25	0.22–0.27
Rms value, in.	0.23	0.25
Standard deviation, σ, in.	0.011	0.014
σ/rms ratio, %	4.65	5.46
Ductility ratio	0.398	0.223

column were obtained from a 20-weld sample made using $^5/_{16}$-in. continuous radius domed electrodes with an electrode force of 500 lb, and a welding current of 16,200 amp. The data shown in the left-hand column were obtained from a 20-weld sample made using 2-in. continuous radius domed electrodes with an electrode force of 650 lb and a welding current of 13,900 amp. The current value of 13,900 amp was deliberately chosen to provide an average weld diameter as near as possible to the minimum acceptable value of 0.18 in.

Under the above conditions, the consistency of the welds made with the 2-in. continuous radius domed electrode appears only slightly better than that of welds made with the $^5/_{16}$-in. continuous radius domed electrodes (i.e., lower values of standard deviation to rms values of the properties listed). However, inspection of the strength-current curve for the 2-in. continuous radius domed electrodes (Fig. 7) reveals that the choice of 13,900 amp as a welding current is well below optimum and it is believed that far better consistency would result at the optimum current value.

Another factor of interest in evaluating spot welds is the so-called ductility ratio. This ratio, defined as the ratio of the normal-tension strength to the tensile-shear strength, is considerably greater for welds made without flashing. For convenience, these values have been listed under the appropriate column at the bottom of Tables 4 and 5. Thus, the welds made without flashing exhibited ductility ratios of 0.398 and 0.364, while those made with flashing exhibit ductility ratios of 0.223 and 0.227. Since high values of ductility ratio are normally desired, this is taken as further evidence of the desirability of avoiding flashing.

In summary, then, better weld consistency and superior ductility ratios appear to prevail when welding conditions are chosen to avoid flashing at the electrode-to-work interface.

Summary and Conclusions

1. The following welding conditions produced the most satisfactory combination of weld strength, weld consistency and electrode life for as-received, pickled-and-lightly-oiled, auto-body stock of nominal 0.036-in. thickness:

Electrode material:	RWMA Class 2
Electrode geometry:	2-in. radius continuous dome on $^5/_8$-in. diam electrodes
Electrode force:	600–700 lb
Welding time:	12 cycles ($^1/_5$ sec.)
Weld current:	15,000–16,000 amp
Weld spacing:	2-in., center-to-center

2. With 0.039-in. material (34,800 psi yield strength, 47,600 psi tensile strength), the above conditions produced more than 2000 welds having tensile-shear strengths of 1400 ± 100 lb, and weld diameters well above the 0.18 in. as specified in MIL-W-12332 (ORD) specifications with no appreciable flashing at the electrode-to-work interface.

3. The consistency of strength and diameter of welds made under conditions producing no flashing at the electrodes was found to be superior to that of welds made with conditions producing flashing at the electrodes.

4. The consistency of strength and diameter of welds made with a 2-in. continuous-radius domed electrode was superior to that of welds made with $^5/_{16}$-in. continuous-radius domed electrodes. Even though the current used with the 2-in. radius domed electrode was reduced to well below optimum in order to make the weld diameters comparable, the 2-in. radius dome produced more satisfactory results.

Acknowledgment

The authors wish to acknowledge the sponsorship of this experimental investigation by the Welding Research Council of the Engineering Foundation. They are further indebted to the membership of the Series Spot Welding Subcommittee, its chairman, John F. Cantalin, and John F. Randall, chairman of the Resistance Welding Research Committee, for guidance and advice during the investigation.

Reference

1. Nippes, E. F., and Domina, F. H., "Series Spot Welding of 0.036-In. Auto-Body Steel," The Welding Journal, 33 (10), Research Suppl., 535-s to 544-s (1954).

RESEARCH NEWS

Radiography

A new Norelco folder on projection microradiography containing photos and micrographs which illustrate the new instrument and its application, is available from the Instruments Division, Philips Electronics, Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

The text explains how the unit extends the usefulness of light and electron microscope investigations in work which involves metallurgy.

Covered in the folder are these subjects: resolution, magnification, field of view, image quality, kv range, supply stability, lenses, targets, alignment, focusing method, specimen chamber and camera.

Other topics include: stereographs, exposure time, conversion possibilities, absorption analysis, meters and controls, cooling, grounding, power requirements, dimensions and weight.

Nondestructive Testing

Symposium on Nondestructive Testing, STP *No. 213*. 104 pages, 6 by 9 in. Hard cover. Price $2.75. Published by American Society of Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Nondestructive testing as a method of materials inspection has increased in importance in all fields of engineering. This symposium presents the latest and most widely used techniques, together with their applications in various fields.

The papers in this symposium were presented, Sept. 17 and 18, 1956, during the Second Pacific Area National Meeting of the ASTM, Los Angeles, Calif. The symposium was sponsored by ASTM Committee E-7 on Nondestructive Testing. The first session, September 17th, consisted entirely of reports from Committee E-7 and its subcommittees. Papers of general interest and specific industrial application made up the last two sessions.

The cost of testing requiring the destruction of the sample has in many instances become prohibitive. In certain instances, such as large castings, nondestructive testing fulfills a need not otherwise satisfied. This book adds greatly to the fundamental knowledge of nondestructive testing and allows the reader to consider some interesting advanced techniques.

The contents of the book follow.

The Activities of ASTM Committee E-7 on Nondestructive Testing: "Committee E-7—Its Scope and Organization," James H. Bly; "Recommended Radiographic Practice—A Report on

(*Continued on page 276-s*)

BONDING OF CERMET-VALVE COMPONENTS TO METALS

Development of specific techniques for attaching cermets of the cemented-carbide type to Inconel by brazing for high-temperature service is described by authors

BY G. M. SLAUGHTER, P. PATRIARCA AND W. D. MANLY

ABSTRACT. The techniques and procedures utilized to bond cermet-valve components successfully to metals for high-temperature fluid service are described. The cermets studied contained varying percentages of titanium carbide, tungsten carbide, tungsten-titanium complex carbide and niobium-tantalum-titanium complex carbide. The binder materials were primarily nickel and cobalt. The results of wetting tests on these cermets with different brazing alloys are presented, as are photomicrographs of many of the most promising cermet-to-metal joints.

A procedure for attaching cermets is described wherein a nickel or tungsten-base alloy cushion is brazed between the cermet and Inconel to absorb stresses resulting from differential thermal expansion. A direct high-temperature bonding procedure is also discussed in which cermets of the titanium carbide-nickel type are joined to nickel without the use of a separately applied brazing alloy.

Introduction

The proper selection of suitable materials for use in fluid control valves is extremely important to the engineer faced with the problem of fabricating a high-temperature fluid circuit. The ultimate in operational reliability is frequently a necessity, since only the slightest leak of the contained fluid through the valve may be objectionable. The success or failure of the complete system may ultimately depend on the development of a workable valve design and the selection of suitable construction materials.

The additional problem of high-temperature operation imposes definite restrictions on both design and materials of construction. Operational manipulation, for example, must be amenable to the unusual conditions existing at elevated temperatures. The valve-stem and valve-seat materials must possess sufficient rigidity to maintain their shape during service, and must be immune to serious solid-phase bonding. Unconventional fluids, such as liquid metals, may be utilized, thereby requiring the valve components to possess excellent resistance to corrosion.

At operating temperatures above 1000° F, cermet-valve materials appear to be especially attractive. Corrosion tests plus solid-phase bonding experiments on a large number of possible materials by the General Corrosion Group of the Oak Ridge National Laboratory Metallurgy Division have shown these metal-ceramic powder mixtures to be promising.[1]

The successful incorporation of cermet components in valve assemblies must provide for a method of attaching the cermets to a metallic structural material. Fastening of these cermets may be accomplished by several methods. In general, they fall under the categories of mechanically mounting, cementing or brazing. Although each method has specific advantages and disadvantages, the brazing procedure seemed to be the most suitable for the particular high-temperature applications to be encountered.

This report covers the development of specific techniques for attaching cermets of the cemented carbide type to Inconel* by brazing for high-temperature service. The primary problems encountered in producing a successful brazed joint are described, and techniques which have been shown to be suitable in the fabrication of valve components are discussed.

General Properties of Cemented Carbide Cermets and Their Influence Upon Brazing

A survey of the literature quickly revealed that a vast number of cemented carbide compositions are in use today. Most of these compositions were developed for use as carbide cutting tools. The 14 types of cutting tool carbides most commonly used have been given standard designations, and these types, together with typical trade names, have been summarized.[2] Other types of cermets for different applications have also been developed over the years, and these have been given broad classifications in various references.

Slight changes in carbide or metallic binder composition or ratio may produce significant changes in both performance characteristics and brazeability. The chemical compositions of the cermets investigated in this study, along with their coefficients of thermal expansion, are listed in Table 1. It

* Nickel-base alloy, nominal composition—78.5% Ni, 14.0% Cr and 6.5% Fe.

Table 1*—Composition of Cermets

Cermet No.	Composition, Wt. % W	Ti	Nb	Ta	C	Co	Ni	Mo	Thermal coefficient of expansion ($\times 10^{-6}$/° F) (20–1200° F)
1	...	58.3	7.5	0.5	15.0	18.7	...	..	4.5
2	...	58.3	7.5	0.5	15.0	...	18.7	..	4.3
3	...	52.1	4.5	0.3	13.1	...	30.0	..	5.3
4	...	52.1	4.5	0.3	13.1	...	25.0	5	5.3
5	68.5	6.7	1.7	5.4	6.7	10.75	...	..	4.0
6	80.6	...	0.6	1.4	5.4	11.75	...	..	3.1

* Compiled from manufacturer's literature.

G. M. Slaughter, P. Patriarca and W. D. Manly are associated with the Metallurgy Division of the Oak Ridge National Laboratory.

Paper presented at AWS 1958 Annual Spring Meeting held in St. Louis, Mo., April 14–18.

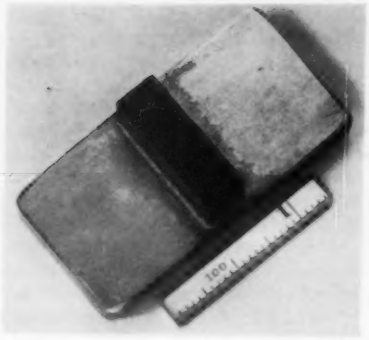


Fig. 1 Cermet-to-nickel wettability specimen

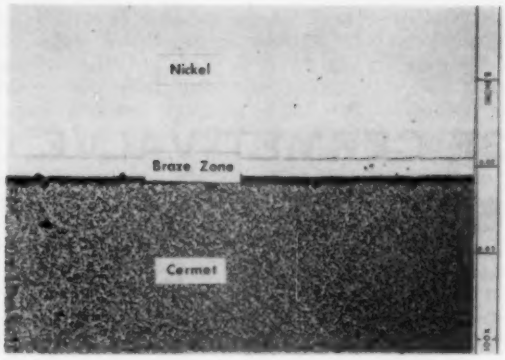


Fig. 2 Cermet No. 2 brazed to nickel with "Electroless-plated" nickel and electroplated copper. Etch, none

may be noted that they generally contain varying percentages of titanium carbide, and/or tungsten carbide, with minor additions of niobium- and tantalum-containing complex carbides. The binder materials are primarily nickel and cobalt. Each cermet possesses its own characteristic properties for a high-temperature valve material and each poses a unique attachment problem.

The brazing of cemented carbides is complicated by the fact that many are relatively difficult to wet. The tungsten carbide-metal cermets are probably the easiest to wet of the combinations listed. The other carbide additions appeared to hinder wetting, and the cermets containing a high percentage of titanium carbide were found to be extremely difficult to braze with conventional procedures.

Another factor complicating the production of satisfactory brazed joints between cermets and conventional structural materials is the wide difference in coefficients of thermal expansion. The coefficient of thermal expansion for a typical cermet, No 2 in Table 1, is approximately 4.3×10^{-6} in./in./° F, while the coefficient for Inconel is 8.5×10^{-6} in./in./° F (over 0–1200° F range). These differences in the thermal-expansion coefficient can easily create sufficient stresses during cooling from the brazing temperature to result in fracture of the bond or cermet unless special precautions in procedure or designs are made.

The problem of attaching the various cermet-valve components necessitated an investigation of their response to wetting by various high-temperature brazing alloys. Sample cermet-to-nickel joints were brazed in −80° F dewpoint hydrogen with several conventional brazing alloys and the degrees of bonding are recorded in Table 2. A photograph illustrating the degree of filleting obtained when Cermet No. 3 is brazed to nickel with Alloy B shown in Fig. 1.

It can be seen from Table 2 that all of the alloys adequately wet the Cermet No. 6, which contains a high percentage of tungsten carbide. Cermet No. 5, which contains more of the other carbide-forming constituents, was wet by all but the copper. The cermets containing large percentages of titanium

Table 2—Results of Bonding Tests

Brazing alloy	*Composition, wt %*	*Brazing temperature, ° F*	*Cermet No.* 1	2	3	5	6
A	91.2Ni – 4.5Si – 2.9B – 1.4Fe	1920	Fair	Fair	Fair*	Good	Good
B	93.2Ni – 3.5Si – 1.9B – 1.4Fe	2050	Fair	Fair	Fair	Good	Good
C	73.2Ni – 13.5Cr – 4.5Si – 3.5B – 4.5Fe – 0.8C	2150	Fair	Fair	Good	Good	Good
D	100 Cu	2050	Poor	Poor	Poor	Poor	Good
E	82Au – 18Ni	1830	Poor	Poor	Poor	Fair	Good
F	60Pd – 40Ni	2280	Good	Good	Good	Good	Good
G	70Ni – 10Si – 20Cr	2150	Poor	Poor	Poor	Good	Good
H	90Ni – 10P	1830	Fair	Poor	Poor	Good	Good

* Poor, wetting only at contact points. Fair, intermittent filleting—little spreading on cermet. Good, continuous filleting—extensive spreading on cermet.

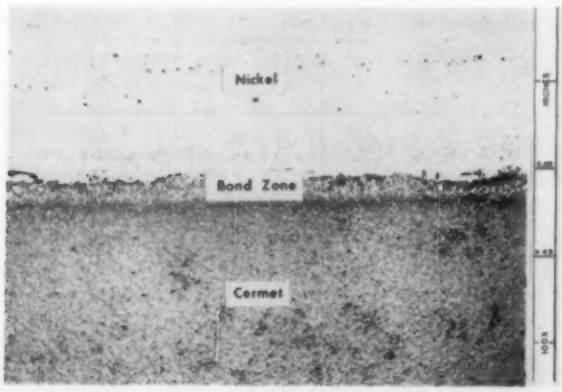


Fig. 3 Cermet No. 2 joined to nickel by high-temperature bonding. Etch, none

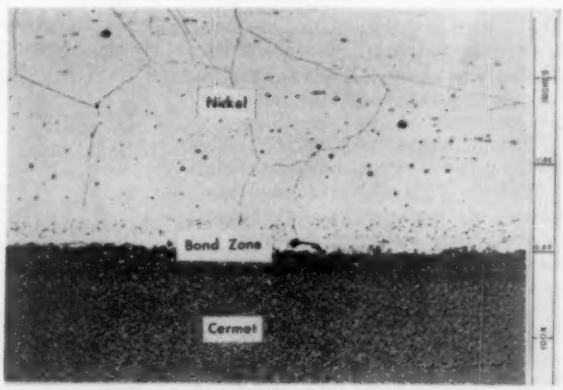


Fig. 4 Cermet No. 2 joined to nickel by high-temperature bonding. Etch, chrome regia

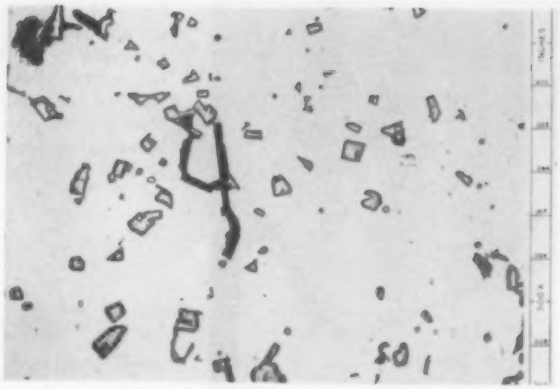


Fig. 5 Microstructure of fillet formed by high-temperature bonding Cermet No. 2 to nickel. Etch, none

Fig. 6 Microstructure of fillet formed by high-temperature bonding Cermet No. 2 to nickel. Etch, none

carbide were adequately wet only by the nickel-silicon-boron-iron, the nickel-chromium-silicon-boron-iron and the palladium-nickel alloys.

The wettability of the nickel-phosphorus alloy on the titanium-carbide cermets was improved significantly when it was preplaced on the cermet as an Electroless plate.[4,5] A relatively tough joint was obtained by the use of an electrolytic copper plate over the Electroless plate. Upon brazing, the nickel-phosphorus alloy melts at approximately 900° C and prewets the sintered carbide cermet as well as the copper overlay. At a higher temperature the copper melts and dilutes the characteristically brittle Electroless-plated alloy, thereby producing a ductile braze. A photomicrograph of the joint made in this manner is shown in Fig. 2. This procedure was suitable in most cases but occasional lack of wetting, attributable to inconsistencies in the plating process, made the development of a more consistent technique highly desirable.

Experiments on valve components indicated that conventional high-temperature brazing procedures generally were not adequate. As indicated previously, the large differences in thermal-

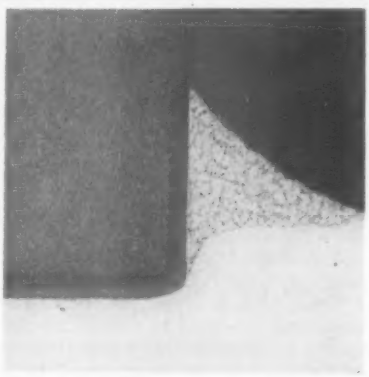


Fig. 7 Cermet No. 4 joined to nickel by high-temperature bonding. Etch, none

expansion coefficients between the very hard cermet and the strong high-temperature alloy, Inconel, often resulted in fracture of the cermet. As a means of cushioning the stresses built up in the cermet from this differential expansion, a $^1/_4$-in. thick nickel sandwich was brazed between the cermet and the Inconel. Upon slow cooling from the brazing temperature, the nickel yields sufficiently to absorb a major portion of these stresses.

Experiments on the larger components also indicated that the characteristics of the brittle nickel-base brazing alloys sometimes significantly minimized the benefits of the nickel cushion. The unfavorable expansion coefficients (Brazing Alloy A—7.6 × 10^{-6} in./in./° F)[6] might result in stresses of such a magnitude as to cause cracking in the cermet or at the bond. Consequently, an attachment procedure was developed wherein a nickel screen, impregnated with the alloy A, was placed on the faying surface of the cermet. After brazing, the majority of the brazing alloy was removed by grinding, leaving approximately a 0.0005-in. layer. This prewet cermet was then copper-brazed to the nickel cushion, with the copper acting both as the major source of filler metal and as a diluent for the brittle nickel-base brazing alloy. This technique was used successfully in the construction of a valve component, but the somewhat complicated procedure led to further studies of simpler bonding methods.

Another procedure was developed which has been proved satisfactory for attaching the titanium carbide-nickel cermet valve components to their Inconel housings. This method elimi-

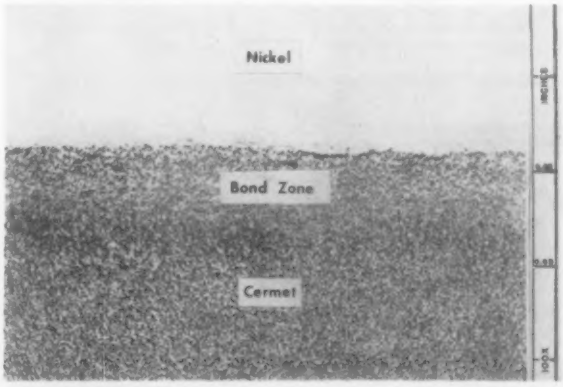


Fig. 8 Cermet No. 4 joined to nickel by high-temperature bonding. Etch, none

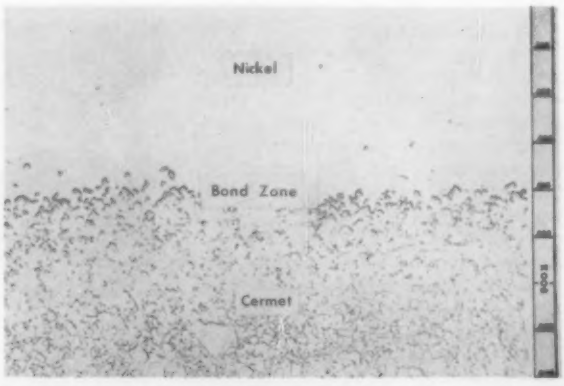


Fig. 9 Cermet No. 4 joined to nickel by high-temperature bonding. Etch, none

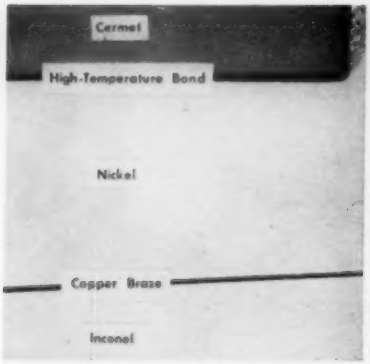


Fig. 10 Composite photograph of cermet-to-nickel-to-Inconel joint (Cermet No. 2 joined to nickel by high-temperature bonding; nickel joined to Inconel by copper-brazing). Magnification X12. Etch, none. (Reduced by 50% upon reproduction)

nated both the necessity of prewetting the cermet and the subsequent copper braze to the nickel cushion. The cermet was merely placed in intimate contact with the nickel and heated to a very high temperature (approximately 1350° C) in an inert atmosphere. A liquid phase forms at this temperature from the alloying between the two materials, which on cooling, results in a relatively tough, ductile joint. The minimum temperatures for consistent bonding for the three cermet compositions of greatest interest in this group are listed in Table 3.

Table 3—Minimum Temperature for Consistent Direct Bonding of Cermet-Valve Components

Cermet No.	*Binder, %*	*Bonding temperature, ° C.*
2	20 Ni	1350
3	30 Ni	1335
4	25Ni – 5Mo	1340

The microstructure of the bond formed between Cermet No. 2 and nickel is shown in Fig. 3 at × 100 in the as-polished condition. The same sample is shown in Fig. 4 after a light chemical etch. A photomicrograph of the structure of the fillet formed between the cermet and nickel during bonding is shown in Fig. 5. Small particles of carbides and graphite are dispersed in a nickel-rich matrix. An area with an unusually high concentration of graphite is shown in Fig. 6.

A structure of similar appearance is formed from the interaction between the Cermet No. 4 (nickel-molybdenum binder) and the nickel. A photomacrograph of the fillet formed is shown in Fig. 7. The bonds at × 100 and × 500, respectively, are shown in Figs. 8 and 9.

The metallographic examination of the bond indicates the formation of a eutectic structure. The presence of several eutectics in the titanium carbide-nickel system has been reported and a phase diagram was presented.[7]

A photomacrograph of a composite sandwich-type braze is shown in Fig. 10. A Cermet No. 2 sample has been high-temperature bonded to nickel, and the resultant subassembly copper brazed to Inconel. If service in liquid NaK or sodium is to be encountered, the poor corrosion resistance of the copper-braze would be undesirable.[8] In this event, alloys of the nickel-silicon-boron-iron or nickel-chromium-silicon-boron-iron types might be utilized for the nickel-to-Inconel joint.

Fig. 11 Photograph illustrating extensive and nonuniform "settling" resulting from an excessive bonding temperature

Component Fabrication

At the high temperatures required for bonding, the cermets lose strength to such an extent that occasionally significant distortion or warpage of the cermet body is observed. Accelerated alloying may also result from only a slight excess in bonding temperature. This condition is shown in Fig. 11 in which extensive and nonuniform "settling" of a small test sample was obtained upon heating at 1370° C for 10 min.

Accordingly, a specialized procedure was developed to permit detection of the initiation of liquid formation. The optimum temperatures listed in Table 3 were found to vary slightly with different components of the same general composition. This observation can probably be related to variations in the compacting and sintering procedure in

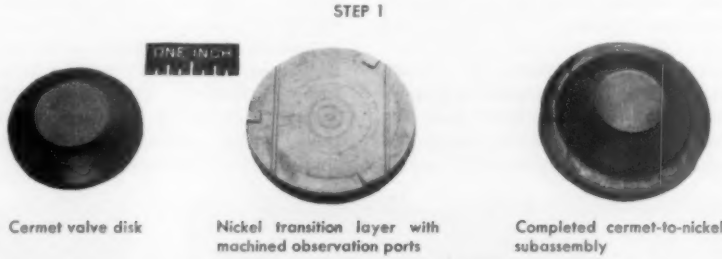


Fig. 12 Assembly procedure for attaching cermet to nickel cushion

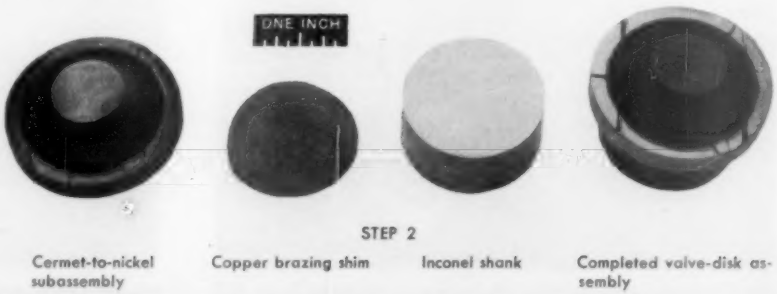


Fig. 13 Assembly procedure for attaching cermet subassembly to Inconel shank

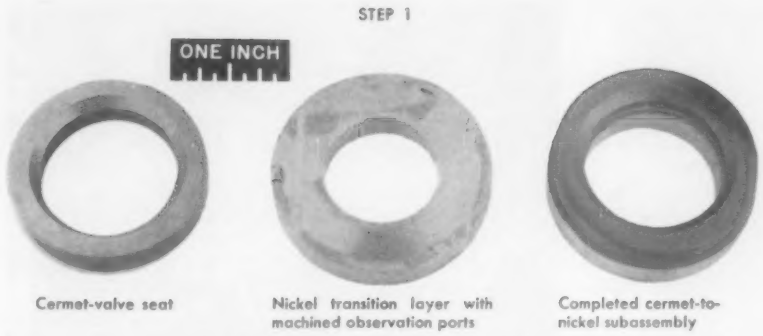


Fig. 14 Assembly procedure for attaching cermet to nickel cushion

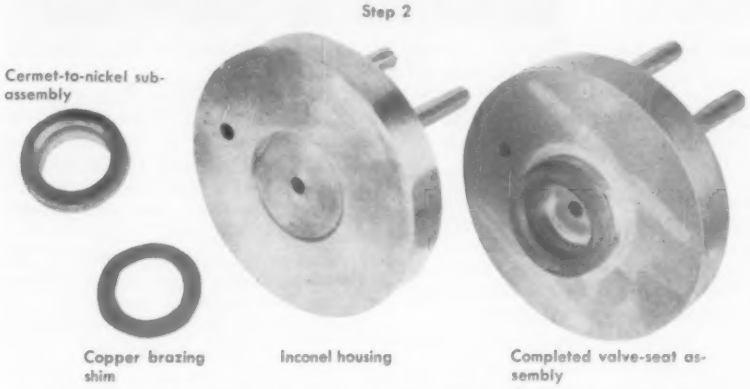


Fig. 15 Assembly procedure for attaching cermet assembly to Inconel housing

the original manufacture of the cermet bodies. Therefore, each component was treated as an individual problem.

Observation ports were machined in the nickel transition layer to permit a visual determination of the initiation of bonding. This visual observation was found to be an essential addition to the precise control and measurement of temperatures for the consistent prevention of distortion of the cermets. These ports are clearly visible as black spots when the assembly in the furnace hot-zone is viewed with dark glasses. When the liquid phase forms, however, these ports are filled and disappear with the simultaneous formation of a fillet which can also be detected by careful observation through dark glasses. Slow cooling rates were used to minimize stresses during cooling. Slight variations in settling which were observed occasionally were easily compensated for by a machining operation on the nickel face of the cermet-to-nickel subassembly.

Exploded views of the two steps employed in the fabrication of the valve disks are shown in Figs. 12 and 13. The cermet-to-nickel subassembly in the latter figure was copper-brazed to the Inconel shank by conventional dry-hydrogen techniques. Cooling rates of approximately 400° C/hr were used to prevent cracking. The stages used in the fabrication of the valve seats are shown in Figs. 14 and 15.

Attempts to bond the titanium carbide-cobalt cermets to nickel by the direct contact method described previously were unsuccessful. No significant bonding was attained, even at temperatures up to 1400° C.

Consequently, the use of conventional high-temperature brazing procedures was necessitated. The wetting tests reported in Table 2 indicated that the 60Pd – 40Ni alloy, melting at approximately 1240° C, consistently exhibited satisfactory flow. Consequently, this alloy was utilized in the fabrication of Cermet No. 1 valve components for the testing programs at ORNL.

The use of a nickel cushion between the cermet and Inconel did not prove to be entirely satisfactory for the joining of this material. It sometimes provided sufficient restraint to crack the cermet. This undesirable condition was remedied by substituting a relatively tough low-expansion tungsten-base alloy* for the nickel. This tungsten-copper-nickel powder-metallurgy alloy is reported to have a thermal-expansion coefficient of 4.0×10^{-6} in./in./° F as compared to 8.5×10^{-6} for nickel and 4.5×10^{-6} for Cermet No. 1.

Photomicrographs of the bond produced by brazing this cermet to the tungsten-base alloy with 60Pd – 40Ni are shown in Figs. 16 and 17.

Cermet No. 5 valve components (tungsten-titanium complex carbides-cobalt binder) have been successfully fabricated by brazing to the tungsten-base alloy with both the 60Pd – 40Ni alloy at 1250° C and the alloy B at 1120° C. The tungsten-carbide portion of this cermet apparently promoted better wetting tendencies than

* Composition—92W – 5Ni – 3Cu.

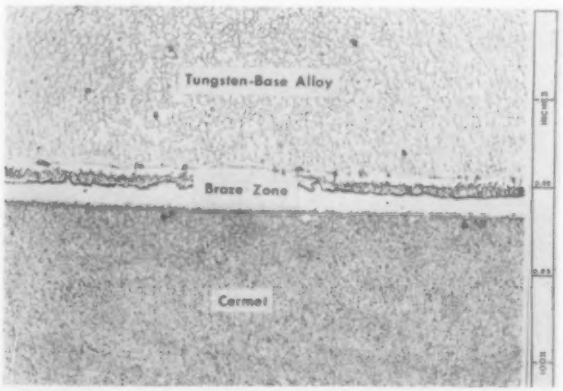


Fig. 16 Cermet No. 1 joined to a tungsten-base alloy by brazing with 60Pd–40Ni. Etch, none

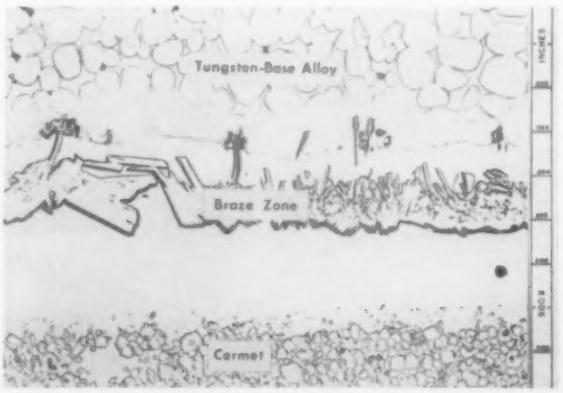


Fig. 17 Cermet No. 1 joined to tungsten-base alloy by brazing with 60Pd–40Ni. Etch, none

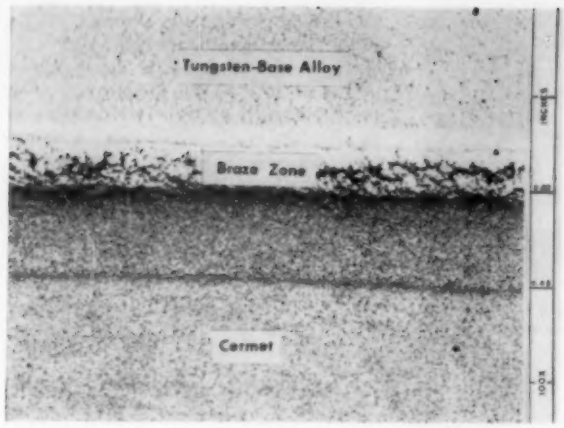


Fig. 18 Cermet No. 5 joined to tungsten-base alloy by brazing with 60Pd–40 Ni. Etch, none

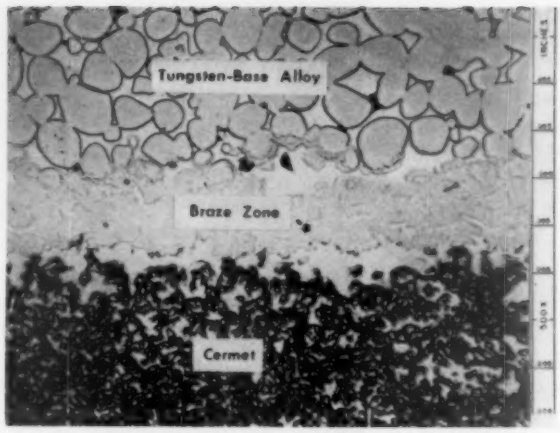


Fig. 19 Cermet No. 5 joined to tungsten-base alloy by brazing with 60Pd–40Ni. Etch, none

were noted in those containing higher percentages of titanium carbide.

Photomicrographs of the 60Pd–40Ni brazed joints at × 100 and × 500, respectively, are shown in Figs. 18 and 19.

Cermets of the tungsten carbide-cobalt type, such as No. 6, were easily wet by a number of conventional high-temperature brazing alloys. Two of these which have been used to fabricate actual components are copper and Alloy B. A nickel cushion was again used as a sandwich material between the cermet and Inconel.

Photomicrographs at × 100 of copper and Alloy B brazed joints, respectively, are shown in Figs. 20 and 21. Good bonding is evident on both joints.

Conclusions

As a result of this investigation, the following conclusions can be made:

1. Cermets containing large percentages of titanium carbide and tungsten carbide with possible minor quantities of solid solutions of carbides of niobium, tantalum and titanium can be successfully joined to Inconel in the construction of high-temperature fluid valves or similar applications.

2. The cermets containing large percentages of tungsten carbide can be wet with several high-temperature brazing alloys.

3. Of the brazing alloys tested, the cermets containing large percentages of titanium carbide were adequately wet only by the nickel-silicon-boron-iron, the nickel-chromium-silicon boron-iron and the palladium-nickel alloys.

4. A high-temperature direct-bonding procedure has been developed for joining titanium carbide-nickel cermets to nickel. The cermet is placed in intimate contact with the nickel and heated to a very high temperature (approximately 1350° C) in an inert atmosphere.

5. The use of a nickel or a low-expansion tungsten-base alloy transition layer between the cermet and the Inconel is beneficial in cushioning the stresses resulting from differential thermal expansion.

Acknowledgment

The authors wish to acknowledge the assistance of Kennametal, Inc., for providing cermet samples and technical information on their properties and compositions.

They also wish to acknowledge the contribution of C. E. Shubert of the Welding and Brazing Group for the preparation of the various components and test specimens required in this study.

They also wish to thank R. A. Bowman, E. P. Griggs and J. C. Gower of the Metallography Section for the metallographic and photographic contributions to this investigation.

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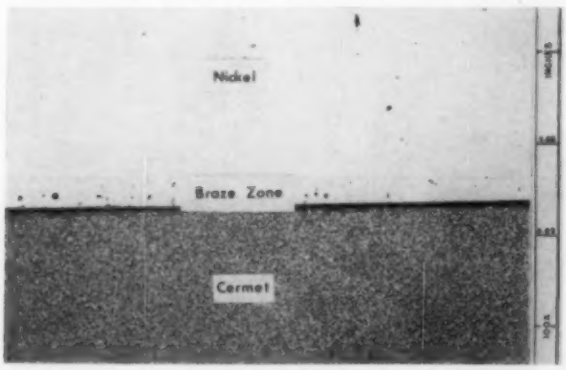

Fig. 20 Cermet No. 6 joined to nickel by copper-brazing. Etch, none

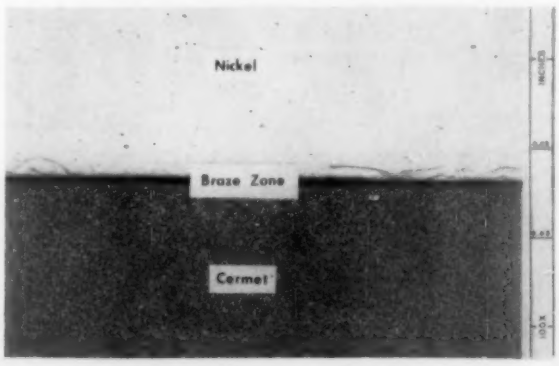

Fig. 21 Cermet No. 6 joined to nickel by brazing with Alloy B. Etch, none

THE ARC WELDING OF WROUGHT MAGNESIUM-THORIUM ALLOYS

Results of evaluation tests on wrought magnesium-base, thorium-containing alloys HK31A, HM21XA and HM31XA, indicate that they possess excellent weldability and good, short-time high-temperature properties after welding

BY L. F. LOCKWOOD AND PAUL KLAIN

ABSTRACT. This paper presents the results of welding evaluation tests on the recently developed, wrought, magnesium-base, thorium-containing alloys, HK31A sheet (Mg – 3.3% Th – 0.7% Zr), HM21XA-T8 sheet (Mg – 2.0% Th – 0.6% Mn) and HM31XA extrusions (Mg – 3.0% Th – 1.5% Mn).

These alloys possessed excellent weldability and retained high strengths at elevated temperatures after welding. The strengths of the welds were equal to, or closely approached, the strengths of the base metals at elevated temperatures. The creep resistance of the alloys was not adversely affected by welding. Postweld heat treatments did not improve the weld strength to any marked degree. The corrosion rates in 3% NaCl solution were not changed significantly by welding. EZ33A alloy, (Mg – 2.7Zn – 3.0 RE – 0.7Zr) is the best rod composition for all the alloys. HM31XA rod may be more advantageous in certain applications at temperatures above 600° F. The marked undercutting tendencies during welding could be overcome by special techniques, such as preheating, grooved backing plates and inert-gas backing. The low level of radioactivity of thorium in these alloys is of minor consideration and is easily controlled by proper procedure.

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Paper presented at the 1958 AWS Annual Spring Meeting held in St. Louis, Mo., April 14–18.

Introduction

Because of their excellent strength-to-weight ratio, magnesium alloys are finding increasing uses in present-day aircraft and missile parts. Until recently, their uses had been confined chiefly to room-temperature applications. Now, with the trend to extremely high speeds in aircraft and missiles, the demand for lightweight materials with high strengths at elevated temperatures has increased markedly. To meet this need, a series of new magnesium alloys containing up to 3.5% thorium in combination with Zn, Zr and Mn in the form of sheet, plate, extrusions and castings, has been developed. The characteristics and properties of these alloys have been fully covered in a recent article by T. E. Leontis.[1] Brief reference to their welding characteristics and properties has also appeared in recent literature.[2, 3]

This paper will present, in more detail, the wrought-alloy arc-welding characteristics and the properties of the welds at room and elevated temperatures.

Mechanical Properties and Characteristics of Alloys

The new thorium-containing wrought alloys are useful for applications at temperatures in the range of 300 to 900° F. They possess good creep resistance up to 700° F and good short-time tensile properties up to 800 or 900° F. The older conventional alloys are normally useful for applications at temperatures up to 300 to 400° F. The analyses and properties of both the old and the new alloys are listed in Table 1.

HK31A sheet and plate are available in the -H24 or the -0 temper, but the former is more widely used. HM21XA is available only in the -T8 temper, which is a strain-hardened and aged condition. Its high temperature properties and creep strength are superior to HK31A above 500–550° F.

The short-time tensile properties of the various sheet alloys at different temperatures are shown in Figs. 1 and 2. AZ31B-H24 has the highest room-temperature and the lowest elevated temperature properties. HK31A has the highest properties of the thorium-

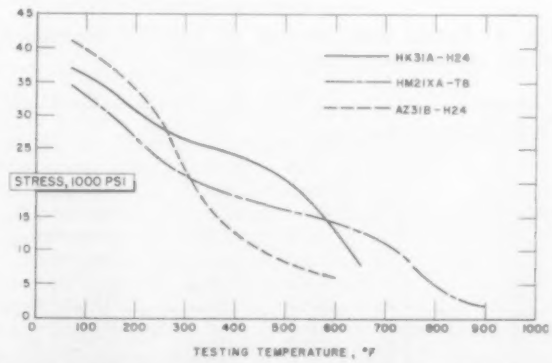


Fig. 1 Tensile strength of magnesium sheet alloys; 0.040–0.250-in. sheet

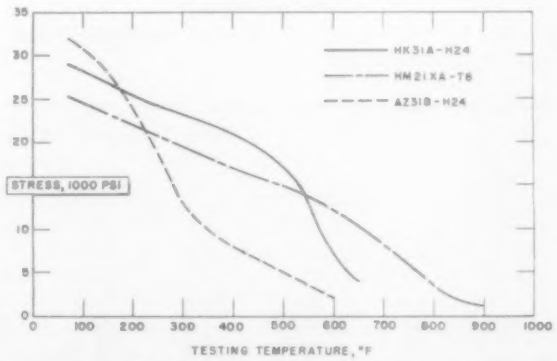


Fig. 2 Tensile yield strength of magnesium sheet alloys; 0.040–0.250-in. sheet

Table 1— Composition and Properties of Wrought Magnesium Alloys

ASTM designation	Temper	Composition range, % Th	Mn	Zr	Al	Zn	Freezing range, °F	70° F tensile properties 1000 psi TS	TYS	CYS	% E
				Sheet alloys							
HK31A	H24	2.5–4.0	...	0.45–1.0	...	...	1092–1195	38	30	23	8
HM21XA	T8	1.5–2.5	0.35–0.80	...	...	...	1121–1202	34	25	15	10
AZ31B	H24	...	0.2 min	...	2.5–3.5	0.7–1.3	1050–1160	42	32	26	15
				Extrusion alloys							
HM31XA	F	2.5–3.5	1.2 min	...	...	...	1121–1195	42	33	27	10
AZ31B	F	...	0.2	...	2.5–3.5	0.7–1.3	1050–1160	38	29	14	15
ZK60A	T5	...	...	0.45 min	...	4.8–6.2	930–1175	53	44	36	11
AZ80A	F	...	0.15 min	...	7.8–9.2	0.2–0.8	910–1130	49	36	32	11

containing alloys at temperatures up to 500° F, but above 600° F, HM21XA-T8 shows a decided superiority.

The tensile properties of HM31XA alloy and the three conventional extrusion alloys are shown in Figs. 3 and 4. The superiority of HM31XA at temperatures over 300° F is evident.

The superiority of the thorium-containing alloys in resistance to creep at elevated temperatures is even more pronounced than that of their tensile properties.[1]

Procedure

The welding tests were made with the inert-gas-shielded tungsten-arc process, using an a-c high frequency-stabilized source of power and helium shielding gas. No special precautions other than a suction hood to remove the welding fumes were required. No special protection of the underside of the weld bead was used in these tests. All materials were prepared by wire-brush cleaning both surfaces and the edges prior to welding.

Evaluation of welds consisted of static tensile tests at room and elevated temperatures, creep properties and corrosion characteristics. The tensile properties were determined on standard 2-in. gage length and $^1/_2$-in. reduced-section test bars with the weld bead in the middle of the specimen transverse to the direction of testing. Tensile yield strength and percent elongation were determined over the 2-in. gage length. Strain rate for the room and elevated temperature static tests was 0.005 in./in./min to the tensile yield strength and 0.10 in./in./min to failure. Specimens tested at elevated temperature were heated to the test temperature in approximately 45 min using a tubular furnace. Temperature, as indicated by a thermocouple held at the middle of the specimen by asbestos tape, was controlled to within ± 2° F of nominal test temperature. The tests were made with the bead left on and with it machined flush with the sheet surfaces.

Results and Discussion

Weldability

The weldability or the weld cracking tendency of the thorium-containing alloys was determined by the use of the testpieces shown in Fig. 5. The circular-bead test was used for evaluating sheet, and the triangle test, for evaluating extrusion alloys. These tests have given excellent correlation with production experience in the past and have been used as standard tests for the preliminary evaluation of all experimental magnesium alloys to date.

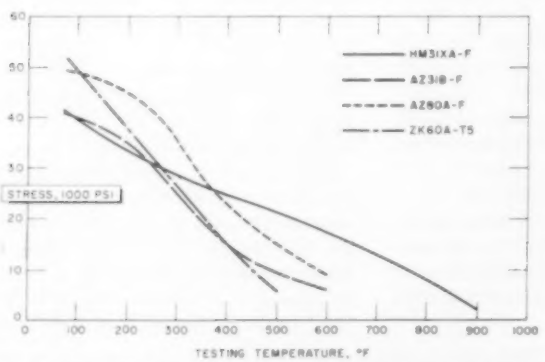


Fig. 3 Tensile strength of extruded magnesium alloys; extruded bars, rods and shapes

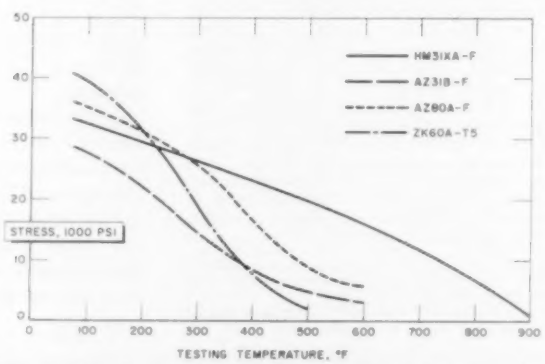


Fig. 4 Tensile yield strength of extruded magnesium alloys; extruded bars, rods and shapes

Table 2— Tensile Properties of All-Weld-Metal Deposits

Test temperature, °F	EZ33A % E	EZ33A 1000 psi TYS	EZ33A 1000 psi TS	HK31A % E	HK31A 1000 psi TYS	HK31A 1000 psi TS	HM31XA % E	HM31XA 1000 psi TYS	HM31XA 1000 psi TS	Alloy on which rod was deposited
70	9.0	17.8	32.0	...	...	...	...	...	...	HK31A
70	3.5	19.8	26.8	10.5	13.8	26.0	1.0	16.9	21.4	HM31XA
70	6.3	21.2	30.0	13.3	13.8	27.0	4.5	10.2	19.3	HM21XA
400	31.5	14.5	21.6	30.0	10.0	17.3	23.3	8.8	15.7	HM21XA
600	50.0	11.0	13.5	32.0	9.5	14.5	24.0	10.5	13.3	HM21XA
700	44.0	6.2	7.4	53.5	5.3	7.6	18.5	7.9	9.4	HM21XA
800	52.0	3.0	4.3	93.5	3.1	4.0	19.5	6.5	7.3	HM21XA

Table 3—Room-Temperature Properties of Welds in Wrought Magnesium Alloys Containing Thorium

Material thickness, in.	Weld rod	Bead on: % E	Bead on: 1000 psi TYS	Bead on: 1000 psi TS	Bead on: % efficiency	Bead on: Location of fracture	Bead off: % E	Bead off: 1000 psi TYS	Bead off: 1000 psi TS	Bead off: % efficiency	Bead off: Location of fracture
				HK31A-H24 sheet							
0.064	HK31A	1.0	24.3	29.0	79	HAZ	3.0	...	29.1	79	W
	EZ33A	3.0	20.2	32.7	88	HAZ	5.0	18.4	30.4	82	W
0.125	HK31A	1.5	20.9	28.4	77	HAZ	...	...	...	...	...
				HM21XA-T8 sheet							
0.040	HK31A	1.5	23.1	31.2	86	HAZ	...	...	...	...	...
	EZ33A	1.8	24.5	31.6	87	HAZ	...	...	...	...	...
	HM31XA	2.0	20.4	27.8	76	HAZ	...	...	...	...	...
0.064	HK31A	1.5	21.7	27.0	77	HAZ	4.3	16.5	27.7	79	W
	EZ33A	1.5	22.5	31.0	88	HAZ	3.0	20.3	30.5	87	W
	HM31XA	1.5	17.8	26.1	74	HAZ	2.0	13.7	24.6	70	W
0.125	HK31A	1.5	17.2	24.3	73	HAZ	5.8	14.4	26.7	81	W
	EZ33A	1.5	21.8	26.7	81	HAZ	3.5	17.9	29.4	89	HAZ
	HM31XA	1.8	16.6	26.4	80	HAZ	2.0	14.3	24.5	74	W
				HM31XA extrusions							
0.125	HM31XA	0.5	20.8	23.4	56	HAZ	3.5	15.5	27.2	65	W
	EZ33A	1.0	25.5	29.7	71	HAZ	2.5	19.9	31.8	76	W
0.375	HM31XA	...	...	...	...	...	2.3	13.8	23.7	56	W
	EZ33A	...	...	...	...	...	3.0	19.8	32.7	78	W
0.625	HM31XA	...	...	...	...	...	2.5	15.8	24.5	58	W
	HK31A	...	...	...	...	...	2.7	16.0	24.0	57	W
	EZ33A	...	...	...	...	...	1.8	19.6	29.9	71	W

W = Weld; HAZ = Heat-affected zone.

The thorium-containing alloys have shown no tendency to cracking in the circular bead and the triangle tests with a variety of rod alloys. The excellent weldability of the thorium alloys has been confirmed by many commercial applications. Since no weld cracking occurred on these thorium-containing alloys, actual test data were omitted. Welding rod composition was not critical but the selection was narrowed to HK31A, HM31XA and EZ33A on the basis of superior elevated-temperature properties.

Properties of Weld-Metal Deposits

The tensile properties of the all-weld metal deposits of EZ33A, HK31A and HM31XA rods are shown in Table 2. Highest room-temperature strengths were obtained with EZ33A, followed by HK31A and HM31XA. As the test temperature increased, the differences in properties between the rod alloys decreased. At temperatures above 400° F, the tensile strengths of EZ33A and HK31A weld deposits on HM21XA plate became essentially equal. At 600° F, the strengths of all three alloys were nearly equal, but above 600° F, the superiority of HM31XA became well-established. On the basis of weld-deposit strengths, EZ33A might be a preferred rod composition for applications up to 600° F, and HM31XA rod might prove more useful at temperatures above 600° F.

Tensile Properties of Welds at Room Temperature

The tensile properties of welded sheet and extrusion alloys as determined at room temperature are given in Table 3.

For HK31A, property data for only the -H24 temper are given, since the -0 temper has had limited use to date. Property data for welds with HM31XA rod were not obtained because of undercutting and low-strength disadvantages, which would preclude its use for production welding of HK31A sheet. Weld strengths of about 29,000 psi with efficiencies of 75 to 80% were obtained with HK31A rod, while with EZ33A rod the weld strengths exceeded 30,000 psi with efficiencies of 80 to 88%.

Highest weld strengths in HM21XA-T8 were obtained with EZ33A rod, followed by HK31A and HM31XA. Weld-strength efficiencies were from 80 to 90% with EZ33A, 73 to 85% with HK31A and 70 to 80% with HM31XA rod. The lower properties and efficiencies in the thicker materials were the result of greater annealing by the welding heat and the more severe notch effect when the bead was left intact. The latter effect was apparent from the values with bead on and bead off on 0.125-in. sheet welded with EZ33A rod. In both cases, failure occurred in the heat-affected zone, but the welds with the weld bead machined off had strengths of 29,400 compared to 26,700 psi for welds with the bead left on.

Welds in HM31XA extrusions were found to show trends somewhat similar to those observed in HM21XA. Weld

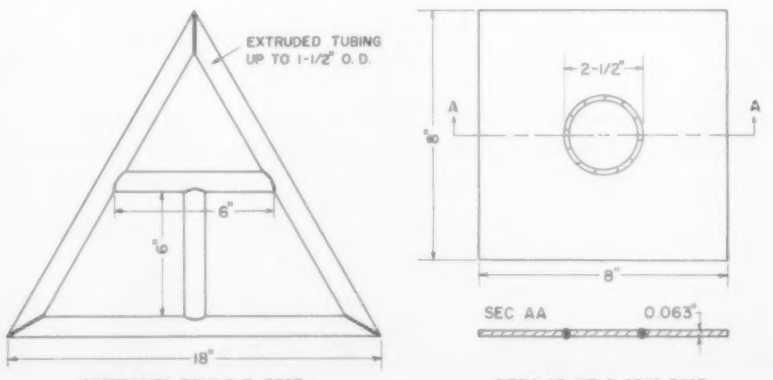


Fig. 5 Weld-cracking testpieces for evaluation of magnesium alloys

strengths with EZ33A rod were approximately 30,000 psi with efficiencies of 71 to 78%, while weld strength with HM31XA rod was 23,400 to 24,500 psi with efficiencies of 56–65%.

Elevated-Temperature Properties of Welds

The short-time tensile properties at elevated temperatures of 0.063-in. HK-31A-H24 sheet welded with EZ33A and HK31A rods are given in Table 4. A plot of tensile strength in Fig. 6 showed that the greatest difference between the base metal and the welds occurred at room temperature, while at temperatures above 400° F, the strengths were essentially equal and the efficiencies approached 100%. Higher weld strengths were obtained with EZ33A than with HK31A rod at room temperature, but above 400° F, no significant difference in strengths between welds of the two rod compositions was evident, regardless of whether the weld bead was left on or removed.

The short-time tensile properties at elevated temperatures of welded HM-21XA-T8 in thicknesses of 0.040 to 0.125 in. are listed in Table 5 and the composite weld-strength data for the three thicknesses welded with EZ33A and HM31XA rods are plotted in Fig. 7. Welds with EZ33A rod had close to 100% efficiencies at temperatures of 400 to 800° F, regardless of whether the beads were left on or machined flush. Welds made by HM31XA rod with the weld bead left intact, had high efficiencies at elevated temperatures, but when the weld bead was removed, the efficiencies were greatly reduced and remained low at temperatures up to 600° F. Since failures were occurring through the deposited weld metal, the low efficiencies were due to the low strengths of the HM31XA weld metal.

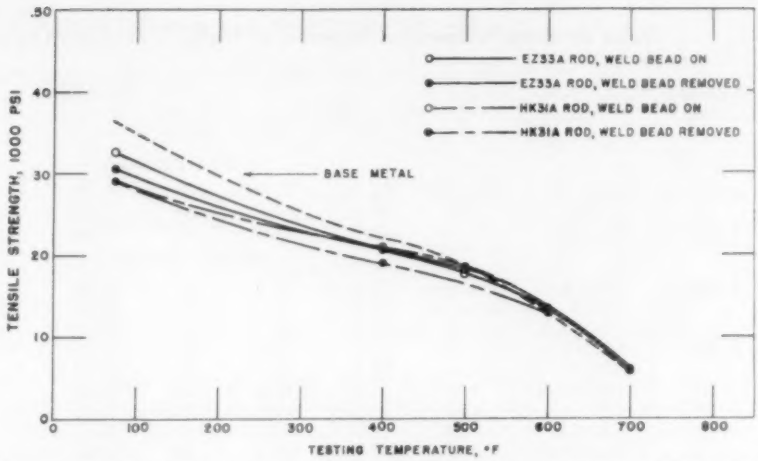


Fig. 6 Tensile strength at elevated temperature of 0.063-in. HK31A-H24 welded with EZ33A and HK31A filler rods

The elevated-temperature properties of HM31XA welds are given in Table 6 and the trend in strength values with temperature and rod compositions is shown in Fig. 8. The superiority of EZ33A rod welds up to 600° F were clearly evident. Strengths of the welds remained below those of the base metal until a temperature of 700° F was reached.

Postweld Aging Treatments

Postweld aging treatments of welds in HM21XA and HM31XA alloys failed to show any marked improvement in properties. The minor effects of aging on the room- and elevated-temperature tensile yield strengths in HM21XA welds are shown in Fig. 9. Even the welds with EZ33A and HK31A rod alloys, which are susceptible to aging, showed no significant improvements at elevated temperatures. Postweld aging of welds in HK31A sheet,

Table 4—Room- and Elevated-Temperature Properties of 0.063-in. HK31A-H24 Sheet Welded with EZ33A and HK31A Rods

Temperature, °F	HK31A rod					EZ33A rod				
	% E	1000 psi TYS	1000 psi TS	% efficiency	Location of fracture*	% E	1000 psi TYS	1000 psi TS	% efficiency	Location of fracture*
Weld bead on										
70	1.0	24.3	29.0	79	HAZ	3.0	20.2	32.7	90	HAZ
400	20.0	13.5	21.0	96	BM	26.0	12.2	20.7	95	BM
500	23.0	13.2	18.6	99	BM	22.5	12.9	17.8	95	BM
600	28.0	9.5	13.3	100	BM	28.5	9.5	13.4	100	BM
700	...	...	...	...	...	58.0	2.9	5.8	100	BM
Weld bead off										
70	...	...	29.1	...	HAZ	5.0	18.4	30.4	83	HAZ
400	...	...	19.1	...	...	18.0	12.4	20.6	94	HAZ
500	...	...	19.4	...	...	23.0	13.0	18.2	97	BM
600	...	...	12.9	...	...	24.0	9.5	13.4	100	BM
700	...	...	...	...	...	51.5	3.0	6.0	100	BM

Base metal

Temperature, °F	% E	1000 psi TYS	1000 psi TS
70	11.5	29.8	36.5
400	28.5	20.5	21.9
500	27.5	16.4	18.7
600	43.5	6.0	13.1
700	77.0	1.5	5.4

* BM = Base metal; HAZ = Heat-affected zone.

Table 5—Room- and Elevated-Temperature Properties of 0.040–0.125-in. HM21XA-T8 Welded with EZ33A and HM31XA Rods

Temperature, °F	HM31XA rod: % E	HM31XA rod: TYS, 1000 psi	HM31XA rod: TS, 1000 psi	HM31XA rod: % E efficiency	HM31XA rod: Location of fracture*	EZ33A rod: % E	EZ33A rod: TYS, 1000 psi	EZ33A rod: TS, 1000 psi	EZ33A rod: % E efficiency	EZ33A rod: Location of fracture*
					Bead on					
75	1.8	18.3	26.8	79	HAZ	1.6	22.9	29.8	85	HAZ
400	4.3	13.0	18.1	94	HAZ	11.2	14.1	18.9	97	HAZ
600	11.8	12.3	14.2	98	BM	11.3	12.1	13.9	97	BM
800	62.2	4.4	6.2	100	BM	59.8	3.6	5.7	100	BM
					Bead off					
75	2.0	14.0	21.3	63	W	3.2	19.1	30.0	88	HAZ
400	4.0	10.1	14.4	81	W	15.5	12.3	17.5	99	HAZ
600	5.8	10.6	13.0	93	W	13.5	10.0	13.2	93	W
800	63.0	3.8	5.4	100	HAZ	44.5	3.4	5.0	100	W

Base metal

Temperature, °F	% E	TYS, 1000 psi	TS, 1000 psi
75	10	25	34
300	20	19	21
400	30	17	18
500	25	15	16
600	15	12	14
700	50	8	11
800	100	3	5

* W = Weld; HAZ = Heat-affected zone; BM = Base metal.

Table 6—Room- and Elevated-Temperature Properties of HM31XA-F Extrusion Welded with EZ33A and HM31XA Rods

Temperature, °F	HM31XA rod: % E	HM31XA rod: TYS, 1000 psi	HM31XA rod: TS, 1000 psi	HM31XA rod: % E efficiency*	HM31XA rod: Location of fracture*	EZ33A rod: % E	EZ33A rod: TYS, 1000 psi	EZ33A rod: TS, 1000 psi	EZ33A rod: % E efficiency*	EZ33A rod: Location of fracture*
					Beads flush					
75	2.5	15.8	24.5	58	W	1.8	19.6	29.9	71	W
400	10.0	10.1	16.9	70	W	22.0	12.5	21.1	88	W
500	13.3	9.7	13.9	66	W	22.0	11.8	17.5	83	W
600	45.3	9.3	12.2	72	W	26.6	8.9	12.6	74	W
700	12.0	10.9	11.7	90	W	14.0	8.6	11.1	85	W
800	19.0	5.6	7.1	89	BM	25.0	6.5	7.6	95	W

Base metal (typicals)

Temperature, °F	% E	TYS, 1000 psi	TS, 1000 psi
75	10	33	42
400	32	23	24
500	25	20	21
600	22	16	17
700	35	12	13
800	60	7	8

* Based on typicals; W = Weld; BM = Base metal.

Table 7—Creep Characteristics of Welded HM21XA-T8 and HK31A-H24 0.063-in. Sheet (Weld Bead On)

Weld rod	400° F: HK31A-H24 *Stress, ksi: 0.1% C	0.2% T.E.	0.5% T.E.	400° F: HM21XA-T8 *Stress, ksi: 0.1% C	0.2% T.E.	0.5% T.E.	600° F: HM21XA-T8 *Stress, ksi: 0.1% C	0.2% T.E.	0.5% T.E.
HK31A	...	...	...	13.6	10.8	14.0	3.9	4.1	4.8
EZ33A	6.5	6.5	11.2	13.2	10.4	14.3	3.7	3.8	5.0
HM31XA	...	...	...	12.0	10.0	13.7	4.6	4.7	5.9
Base Metal	6.5	6.5	10.2	13.3	10.5	13.5	5.0	5.0	6.0

* Stress required to produce indicated creep (C) or total extension (T.E.) in 100 hr. Creep tests were made across the welds on specimens having 2-in. gage length and a 1/2-in. reduced section.

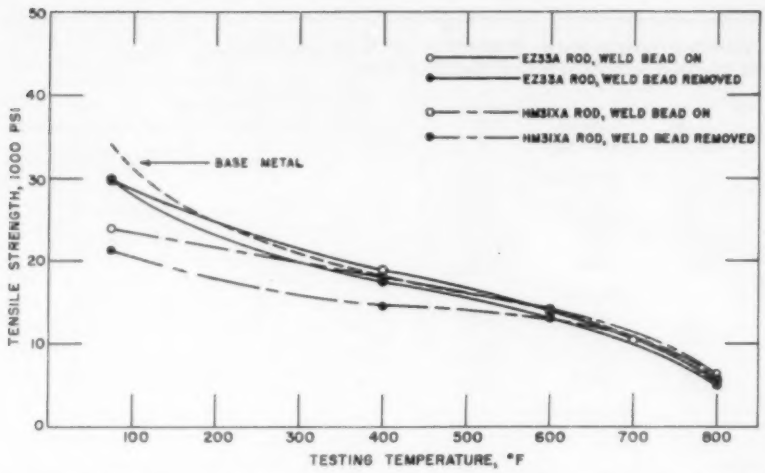


Fig. 7 Tensile strength at elevated temperature of 0.040–0.125-in. HM21XA-T8 welded with EZ33A and HM31XA filler rods

which is readily susceptible to thermal treatments, resulted in an increase of only 2000 to 3000 psi in tensile strength at room temperature after aging 16 hr at 400° F.

Creep Characteristics of Welds

Limited creep data for HK31A and HM21XA welds made with different rods are given in Table 7. At 400° F, the creep resistance of the welds was the same as that of the base metal, regardless of the rod composition. At 600° F, the creep resistance of HK31A welds and base metal were too low to be of any practical importance. However, the creep resistance of HM21XA welds made with HM31XA rod was only slightly lower than that of the base metal, but the creep resistance of welds with HK31A and EZ33A rods were considerably lower. The data also indicated that welds with HK31A and EZ33A rods generally had equivalent creep characteristics.

Tensile Properties of Welded Dissimilar Wrought Alloys

The room- and elevated-temperature short-time properties of HM21XA-T8 welded to HM31XA-F with three different rod alloys are listed in Table 8. Since all the test bars at elevated temperature, and all but one at room temperature, fractured on the HM21XA side of the weld, strength efficiencies were based on the strength of the particular lot of HM21XA-T8 sheet used. Efficiencies of 100% resulted at temperatures of 400° F and above.

The room- and elevated-temperature short-time properties of HK31A-H24 welded to HM21XA-T8 and HM31-XA-F are listed in Table 9. Strength efficiencies, based on the strength of the material in which the failure occurred, were approximately 81% for HK31A to HM21XA and 70% HK31A to HM-31XA at room temperature. At 400° F and above, essentially 100% efficiencies were obtained.

Tensile Properties of Castings Welded to HM21XA-T8 Sheet

The most widely used casting alloys for elevated-temperature service are HK31A, EZ33A and HZ32A (Mg–3.3 Th–2.1Zn –0.7 Zr). Since it is frequently required to weld castings to wrought materials, the three most commonly used castings in the various tempers were welded to $^1/_4$-in. HM21XA-T8 plate with EZ33A rod and their short-time tensile properties determined. The property data are shown in Table 10. Except for room-temperature properties, postweld aging had no significant effect on the weld strengths. Cast-alloy temper had no significant effect on tensile strengths at elevated temperatures. The efficiencies varied somewhat at 400° F, but the ultimate strengths at 400 and 600° F were nearly the same for all cast alloys and tempers.

Welding Techniques

The thorium-containing magnesium alloys exhibited greater oxidizing and undercutting tendencies during welding than the conventional Mg-Al-Zn alloys. As a consequence, the effects of the following techniques to overcome these deficiencies were investigated and compared on 0.040- to 0.125-in. sheet thicknesses: (1) free drop-down in air, (2) grooved backing (3) gas backing (4) preheat, (5) edge gaps and (6) rod composition.

The greater oxidizing tendency of the thorium-containing alloys was manifested chiefly on the underside of the weld by the presence of a dark film, a noticeable parting line where the sheet edges existed, and a highly wrinkled underbead. The oxidation effects were minimized or eliminated by the use of an inert-gas backing, as shown in Fig. 10. The inert-gas backing produced a smooth, oxide-free underbead, which resulted in a reduced notch effect at the junction, maximum strengths and improved consistency. However, with adequate care and preparation, thorium-containing alloys can be welded without the use of inert-gas backing, as is being done on the conventional alloys. The appearance of the underside of the bead made without a protective atmosphere can also be

Table 8—Properties of 0.125-in. HM21XA-T8 Sheet Welded to 0.125-in. HM31XA Extrusion (Weld Bead On)

Weld rod	% *E*	*TYS* (1000 psi)	*TS* (1000 psi)	% efficiency*	*Location fracture*†
		70° F			
EZ33A	1.3	21.9	27.4	84	HAZ-HM21XA
HK31A	1.3	18.6	24.3	74	HAZ-HM21XA
HM31XA	1.5	15.0	22.8	70	HAZ-HM31XA
		400° F			
EZ33A	9.5	14.7	17.6	100	HAZ-HM21XA
HK31A	7.5	13.8	17.3	100	HAZ-HM21XA
HM31XA	6.0	11.3	16.9	98	HAZ-HM21XA
		600° F			
EZ33A	12.5	11.6	13.0	100	BM-HM21XA
HK31A	12.5	11.5	13.0	100	BM-HM21XA
HM31XA	12.5	12.4	13.3	100	BM-HM21XA
		700° F			
EZ33A	21.0	8.1	10.6	100	BM-HM21XA
HK31A	19.0	7.9	10.3	100	BM-HM21XA
HM31XA	19.5	7.9	10.3	100	BM-HM21XA

* Based on strength of HM21XA-T8 sheet.
† BM = Base metal; HAZ = Heat-affected zone.

Table 9– Properties of HK31A-H24 Sheet Welded to HM21XA-T8 Sheet and HM31XA-F Extrusion (Weld Bead On)

Weld rod	Test Temperature, ° F	% E	1000 psi TYS	1000 psi TS	% efficiency*	Location of fracture
0.125-in. HK31A-H24 to 0.125-in. HM21XA-T8						
EZ33A	70	1.0	22.4	26.9	81	HAZ-HM21XA
HK31A	70	1.5	20.8	26.9	81	HAZ-HM21XA
HM31XA	70	1.5	19.8	28.2	85	HAZ-HM21XA
EZ33A	400	11.5	13.6	17.8	100	BM-HM21XA
HK31A	400	7.0	12.4	17.4	98	HAZ-HM21XA
HM31XA	400	7.5	13.3	17.6	99	HAZ-HM21XA
EZ33A	600	28.0	8.1	13.3	100	BM-HK31A
HK31A	600	28.5	8.6	13.0	100	BM-HK31A
HM31XA	600	28.0	8.7	12.4	99	BM-HK31A
EZ33A	700	71.5	4.2	8.1	100	BM-HK31A
HK31A	700	70.5	4.3	7.5	100	BM-HK31A
HM31XA	700	66.0	5.0	7.9	100	BM-HK31A
0.064-in. HK31A-H24 to 0.125-in. HM31XA-F†						
HK31A	70	1.6	23.7	29.2	70	HAZ-HM31XA
HK31A	400	4.5	17.1	21.2	100	BM-HK31A
HK31A	600	10.0	9.6	14.4	100	BM-HK31A

* Based on location of fracture.
† Machined to 0.064 in.
BM = Base metal; HAZ = Heat-affected zone.

improved by fusing it with an arc without rod addition as shown at the bottom of Fig. 10.

The welds in thorium-containing alloys exhibited a more severe undercutting tendency than any of the conventional alloys. Of the three wrought alloys, HK31A showed the least tendency to undercutting. Welding-rod composition, inert-gas backing, grooved backing and preheat were the most effective means of reducing or eliminating the undercutting. The least undercutting was obtained with EZ33A rod, followed by HK31A and HM31XA. Preheat temperatures of 200 to 400° F or inert-gas backing flows of 5–10 cfh in combination with any of the rod compositions effectively eliminated undercutting. Variations in welding techniques did not affect the properties of acceptable welds in thorium-containing alloys. The only conditions affecting weld strengths were the presence of undercutting and offset sheet edges.

Metallography

The typical microstructures of the three wrought thorium-containing magnesium alloys are shown in Fig. 11. HK31A shows a partly recrystallized, work-hardened grain structure, while the HM21XA is a coarser-grained, completely recrystallized, and aged structure. No evidence of precipitate is visible. The HM31XA microstructure is severely deformed and is so extremely fine-grained that even a ×500 magnification has failed to resolve the structure.

The effects of the weld-thermal cycles on the base metals are illustrated in the series of photomicrographs in Figs. 12 and 13. These show the appearance of the junctions at the weld metal-base metal interface. In Fig. 12 are shown the junctions of the three wrought alloys welded with EZ33A rod, while in Fig. 13 are shown the welds with HK31A and HM31XA rods. A narrow zone of complete recrystallization with slight grain growth has occurred in the base metals as a result of the welding heat. This annealing and grain growth explain the somewhat lower room-temperature strengths obtained after welding. The magnitude of the heating effects is dependent on the response of each alloy to the thermal cycles and the duration or repetition of heating during welding. Thus, multiple-pass welds will naturally be subjected to longer heating and therefore greater annealing effects.

From Figs. 12 and 13, it is evident that EZ33A and HK31A welding-rod compositions result in extremely fine-grained welds, while HM31XA results in very coarse-grained columnar deposits. The unusually low room-temperature strengths of HM31XA weld deposits are explained by their ex-

Table 10—Tensile Properties of Various Cast Alloys Welded to 0.250-in. HM21XA-T8 Plate Using EZ33A Welding Rod (Weld Bead Off)

	70° F					400° F					600° F				
Casting	% E	1000 psi TYS	1000 psi TS	% efficiency*	Location of fracture†	% E	1000 psi TYS	1000 psi TS	% efficiency*	Location of fracture†	% E	1000 psi TYS	1000 psi TS	% efficiency*	Location of fracture†
HK31A-F	4.5	13.4	24.7	100	HAZ-C	12.0	11.5	17.3	100	BM-C	20.5	10.0	14.4	100	BM-HM
HK31A-T4	4.8	15.1	27.2	100	HAZ-C	9.0	11.8	17.9	93	HAZ-HM	14.0	10.9	15.0	100	BM-HM
HK31A-T4 + Age[1]	4.5	19.2	32.3	100	W	8.5	12.2	17.8	93	HAZ-HM	14.0	9.8	13.7	96	W
HK31A-T6	5.3	15.7	28.1	88	HAZ-C	10.0	11.3	17.0	86	HAZ-HM	16.0	10.1	14.3	100	BM-HM
EZ33A-F	2.5	19.1	26.7	100	BM-C	8.0	13.2	17.4	90	HAZ-HM	19.0	10.1	13.5	100	BM-C
EZ33A-T5	2.0	17.9	25.1	94	BM-C	7.5	12.8	17.5	91	HAZ-HM	16.5	10.2	12.6	100	BM-C
EZ33A-T5 + Age[2]	3.3	19.6	28.1	100	BM-C	8.5	12.8	17.9	93	HAZ-HM	22.0	9.0	11.4	100	BM-C
HZ32A-F	3.0	15.1	26.8	97	BM-C	15.0	11.3	17.1	100	BM-C	19.5	9.2	11.3	100	BM-C
HZ32A-T5	4.5	16.0	28.7	100	HAZ-C	13.5	10.8	17.0	100	BM-C	17.5	8.9	11.4	100	BM-C
HZ32A-T5 + Age[3]	4.5	16.9	29.9	100	BM-C	14.0	11.2	16.0	84	HAZ-HM	24.0	8.6	11.2	100	BM-C

1. Aged 16 hr at 400° F after welding.
2. Aged 5 hr at 420° F after welding.
3. Aged 16 hr at 600° F after welding.

* Efficiencies are based on original metal strength where fracture occurred. If failure occurred in weld, efficiency was based on strength of weakest metal making up the test bar.

† BM-C = Base-Metal Failure in Casting; BM-HM = Base-Metal Failure in HM21XA-T8 Plate; W = Weld-Metal Failure; HAZ-C = Heat-Affected Zone Failure in Casting.

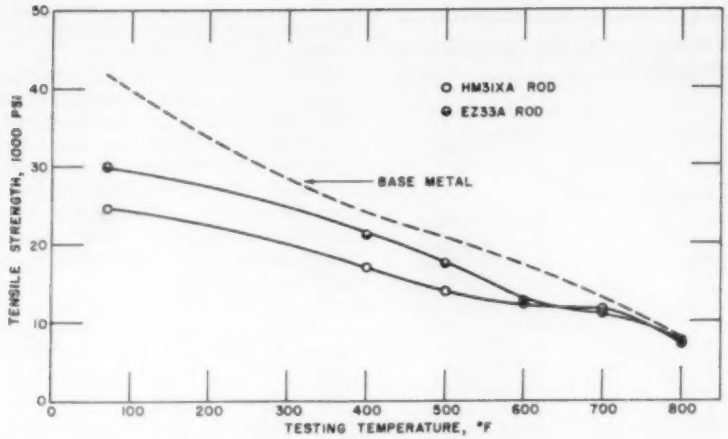


Fig. 8 Tensile strength at elevated temperature of HM31XA-F extrusions welded with EZ33A and HM31XA filler rods. Beads machined flush

Table 11—Corrosion Rates of Various Welded Magnesium-Thorium Wrought Alloys After Alternate Immersion in 3% Salt Solution for 14 Days

	*Corrosion rate, MCD**		
	Base metal		
Weld rod	*HM31XA*	*HM21XA-T8*	*HK31A-H24*
None	0.21	0.21	0.20
EZ33A	0.60	0.21	0.29
HM31XA	0.41	0.21	...
HK31A	0.65	0.21	0.43

* MCD = milligrams/cm²/day.

tremely coarse grains. The appearance of HK31A and HM31XA weld deposits near the center of the weld beads are shown in Fig. 14. The HM31XA grains were not quite so elongated as those at the junction. The lamellar structure seen in deposits in HM21XA was almost completely obliterated on HM31XA base metal due to the repeated heating caused by multipass welding used on this material because of its thickness.

Corrosion

The results of corrosion tests by alternate immersion in 3% salt solution for 14 days are shown in Table 11. While the results indicate an increase in the corrosion rate of HK31A and HM31XA after welding, the actual magnitudes are considerably below commercially significant values and no real significance need be attached to these variations. The only visible form of corrosion attack is pitting at the junction of the weld to the base metal.

Health Considerations

Since thorium is a low-level radioactive element, some concern may be felt about its effects on the health of those working with the magnesium alloys containing thorium. Recent studies[4] of the safety precautions in the handling and fabrication of the magnesium-thorium alloys show that thorium is not a chemical poison and is a comparatively low-level radioactive element. Because of this low radioactivity, the external radiation from the direct handling of the currently used magnesium alloys containing 3% thorium or less presents

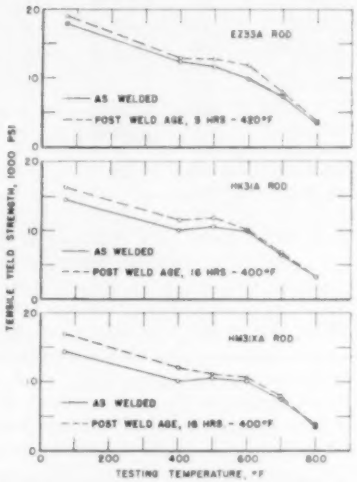


Fig. 9 Effect of postweld aging on tensile yield strength at elevated temperatures of 0.125-in. HM21XA-T8 welded with EZ33A, HK31A and HM31XA filler rods. Beads machined flush

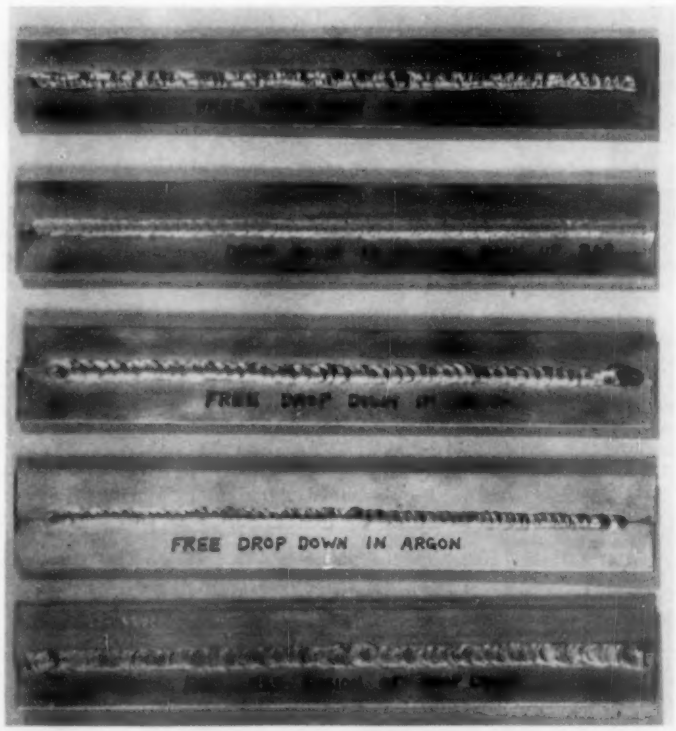
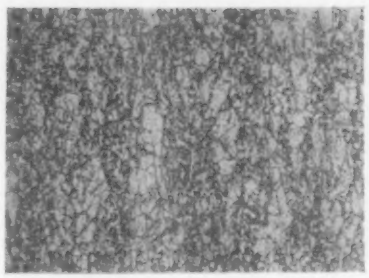
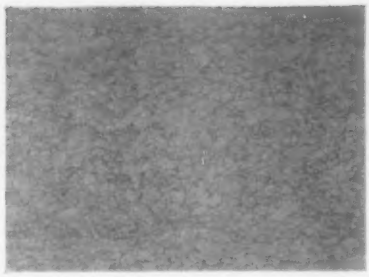


Fig. 10 Effect of various welding techniques on the appearance of the underside of the weld on 0.125-in. HM21XA-T8 using the tungsten-arc process and EZ33A weld rod



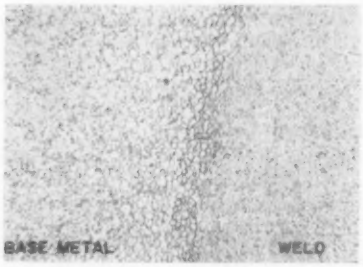
0.125-in. HK31A-H24 sheet. X 250. Partly recrystallized broken-up structure



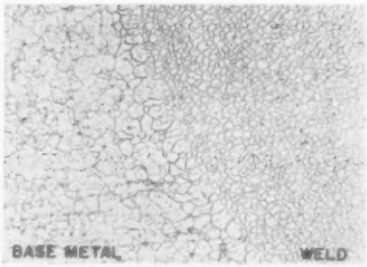
0.063-in. HM21XA-T8 sheet. X 100. Completely-recrystallized and aged structure

HM31XA-F extrusion. X 500. Severely-worked fine-grained structure

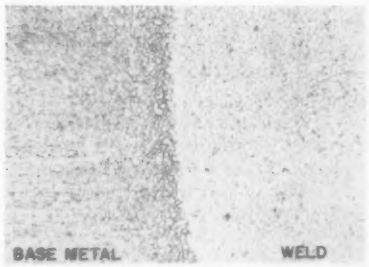
Fig.11 Microstructure of wrought magnesium-thorium alloys. Phospho-picral etch. (Reduced by 40% upon reproduction)



HK31A-H24 base metal. X 100

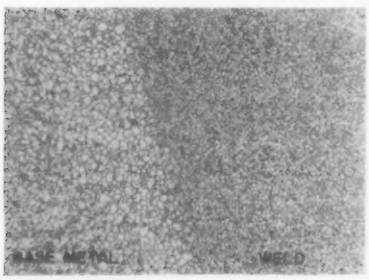


HM21XA-T8 base metal. X 100

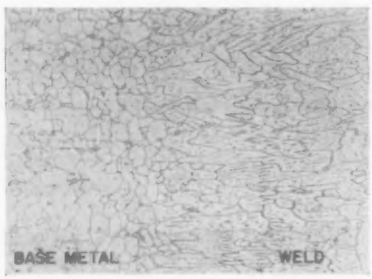


HM31XA-F base metal. X 100

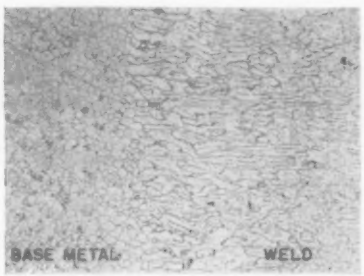
Fig. 12 Weld bead-base metal junction of wrought magnesium-thorium alloys welded with EZ33A filler rod. Phospho-picral etch. (Reduced by 40% upon reproduction)



0.063-in. HK31A-H24 welded with HK31A rod. X 100

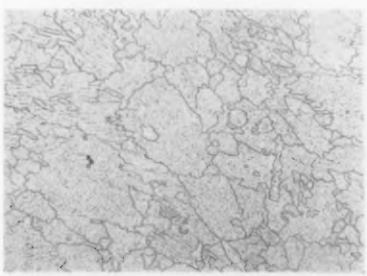


0.125-in. HM21XA-T8 welded with HM31XA rod. X 100

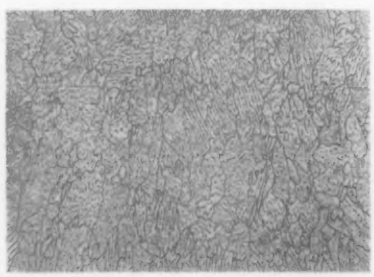


$^{3}/_{8}$ in. HM31XA-F welded with HM31XA rod X 100

Fig. 13 Weld junctions of wrought magnesium-thorium alloys welded with HK31A and HM31XA rods. Phospho-picral etch. (Reduced by 40% upon reproduction)



HM31XA weld deposit in $^{3}/_{8}$-in. HM31XA-F Extrusion. X 100



HM31XA weld deposit in 0.125-in. HM21XA-T8 sheet. X 100

HK31A weld deposit in 0.063-in. HK31A-H24 sheet. X 100

Fig. 14 Appearance of various weld deposits in magnesium-thorium alloys. Etched in phospho-picral. (Reduced by 40% upon reproduction)

no problems. Only continued exposure to high concentrations of fine dust or fumes, as may occur in such operations as welding, grinding, pickling, chemical milling and large scale melting, is hazardous and requires protection of the worker. For most of these operations, the normal precautions for dust or fume control are adequate.

The Industrial Hygiene Standard of 0.1 milligram of thorium per cubic meter of air for continuous exposure has been used as a limiting concentration in the working area. In the welding of magnesium-thorium alloys without any precautions, concentrations of thorium above the 0.1 milligram per cubic meter of air were found in the breathing zone. Use of a local exhaust duct drawing a few hundred cubic feet of air per minute reduced the thorium concentration below the limiting value. Where local exhaust is not practical, and there is sufficient room ventilation to control contamination of the general atmosphere, the welder can be protected by an air-supplied welder's hood or by other means which remove visible fumes from the welder.

Summary

It has been shown that HK31A, HM21XA and HM31XA possess excellent weldability and good, short-time high-temperature properties after welding. Welding resulted in reduced properties at room temperature, especially in HM31XA alloy, but at elevated temperatures, the strengths of the welds were essentially equal to those of the base materials. Limited tests indicated that creep resistance was not significantly affected by welding. Postweld heat treatments resulted in only slight improvements in properties.

It was concluded that EZ33A was the best rod composition. In certain applications at temperatures above 600° F where creep resistance is important, HM31XA rod may be more advantageous. The EZ33A rod composition greatly reduced undercutting, had the highest room-temperature strength and was suitable for welding cast as well as wrought products. In comparison with HK31A rod, it had superior strength at room temperature and equal strength at elevated temperature. The weld strength efficiencies with the different rods at room temperature were as follows:

Base metal	*Strength efficiencies at room temperature of welds with various rods*		
	HK31A	*EZ33A*	*HM31XA*
HK31A-H24	75–80	80–88	...
HM21XA-T8	73–85	80–90	70–80
HM31XA-F	...	71–78	56–65

The corrosion rates of welds varied somewhat with rod composition but the variations were not believed to be significant in relation to service performance.

Satisfactory welding of the thorium-containing alloys to each other as well as to castings was also established. When welding the wrought materials to any of the elevated-temperature casting alloys, EZ33A rod was recommended.

For best results, it might be desirable to use inert-gas backing on the underside of the weld or a trailing shield of inert gas on the top side of the weld to minimize oxidation. However, it was emphasized that the extra protection was not mandatory and equally good results could be obtained without its use.

Acknowledgment

The data on HM21XA have been obtained from the work carried out under the sponsorship of the Materials Laboratory, Wright Air Development Center, USAF, Contract No. AF 33(616)-2337, while part of the data on HK31A was from USAF Contract No. AF (600)-19147. The authors are grateful for permission to publish the information.

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Welding Research Council Bulletin No. 39

by John W. Fisher, George C. Driscoll, Jr., and Lynn S. Beedle

Plastic Analysis and Design of Square Rigid Frame Knees

This Bulletin contains sample calculations and a description of the plastic design of a square knee for a single-span rigid frame.

Welds are designed using the concepts of plastic design as well as those of elastic design in order that the parallelism can be seen.

The methods of design presented can be used as a guide in designing comparable connections for rectangular portal frames.

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TODAY'S TREND IN SHIP RESEARCH

Author discusses some of the significant results from the current program of the only organization in the United States devoted exclusively to ship-hull research

BY DAVID K. FELBECK

SYNOPSIS. Research directed toward ship-hull improvement in the United States has incorporated studies that are more fundamental than was necessary during and just after World War II. The Ship Structure Committee program now includes, for example, low-temperature research on fracture initiation; studies of the influence of prior straining on fracture load; examination of the structure of controlled-rolled steel plate; high-speed measurements of the variations of the strain pattern during crack propagation; and a new fundamental program aimed at achieving more rational design of ships through improved understanding of the interrelations between waves, ship motions, and the resultant loads on and stresses in a ship.

Introduction

No longer can ship research produce an order-of-magnitude reduction in ship failures such as resulted from the studies during and just after World War II. No longer can a ship be considered satisfactory if it can just keep from falling apart, although keeping a ship in one piece was a serious problem not too many years ago (Fig. 1). The early empirical studies effectively revealed those improvements in design, materials and fabrication necessary to reduce to a very low level the catastrophic failure of welded merchant ships and tankers. Thus problems of size, structural loads, seaworthiness and availability of quality materials have displaced brittle fracture as the major applied problems today. Although further refinements have resulted from more recent applied studies, no extensive contributions toward improvement of ship hulls can be expected except from careful and thorough fundamental investigation of several pertinent fields. Thus an examination may be in order of significant results from the current program of the only organization in the United States devoted exclusively to ship-hull research.

The Ship Structure Committee was formed to pool the efforts of four agencies (Coast Guard, Navy, Maritime Administration and American Bureau of Shipping) in ship-hull research. It is assisted in planning and administering a research program by two committees of the National Academy of Sciences-National Research Council: the Committee on Ship Structural Design and the Committee on Ship Steel. With the further help of liaison representatives from organizations such as the Welding Research Council, the Ship Structure Committee research program represents the combined efforts of most United States groups concerned with ship problems. An interpretation of the current trend of this research program may serve to emphasize the importance of fundamental studies to a field as applied as ships. The results of this fundamental work must, of course, be further developed before they can influence ship construction; hence, an appreciable portion of the Ship Structure Committee program has been devoted to applied studies that owe their origins to earlier fundamental results from this or other

David K. Felbeck is associated with the National Academy of Sciences-National Research Council, Washington, D. C.

Fig. 1 Forward half of the Russian-operated American-built Liberty ship *S. S. Valeri Chkalov*, which broke in two in the North Pacific on Dec. 13, 1943

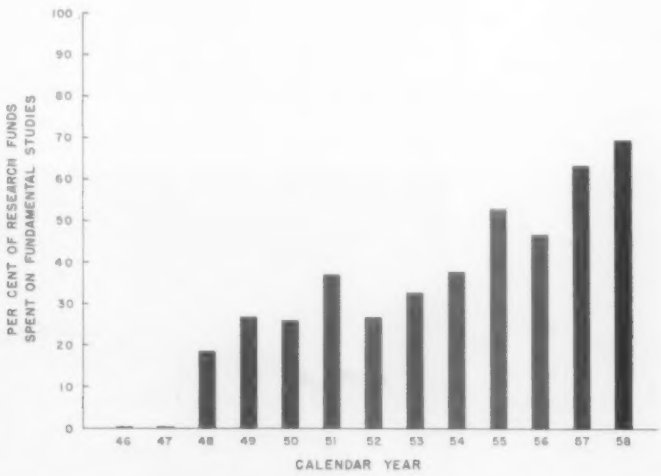

Fig. 2 Percent of Ship Structure Committee research funds spent for fundamental research during each year since 1946

programs. The relative growth of fundamental research within the Ship Structure Committee program since its formation in 1946 is shown in Fig. 2.

Brittle-Fracture Studies

Studies on initiation of brittle fracture have shown that prior cold working of steel plates in tension perpendicular to the direction of the test load can cause a reduction in test load at fracture to about 70% of the load originally required to produce plastic deformation (yield load). If the prior cold working is in compression, the fracture load may be reduced to 59% of yield load. It is possible that these results may help to explain fracture of ships at loads thought to be safely below the yield load. Investigators concerned with fundamentals of crack propagation have shown conclusively that a dynamic strain wave of a magnitude several times the yield strain precedes a rapidly propagating crack. Another investigator is studying independently the relationship of local strain rate to the conditions that are associated with fracture. These projects should help to explain part of the sensitivity of brittle steels to running cracks.

Three projects that are under way or will begin shortly are part of a worldwide study to develop a reliable test for brittleness in steel. A small project nearing completion was set up to find whether there is any correlation between the variation with temperature of the appearance of a laboratory-produced fracture surface on a specimen of ship plate and the temperature at which the ship fractured in service. Because of contradictory reports of the influence of manganese in reducing brittleness in steel, a careful series of experiments is being planned to isolate as well as possible the effect of varying manganese content and to study the influence of this variation on different kinds of tests. The third project is an applied study to assist Commission IX of the International Institute of Welding, which is concerned with brittle fracture, in its current comparison of fracture-appearance tests with energy-absorption tests. This study will be effected through two-way exchange and testing of steel samples of known pedigree.

A comparison of riveted and welded crack arresters has verified that, for equal materials, the riveted arrester is better (because of the discontinuity of the plating), but that flush-welded strips of high notch-tough steel can stop running cracks. The required width of material and properties of the arrester strip have not yet been determined.

An investigation of the influence of metallurgical structure on fracture has obtained additional results on three grades of steel that support an earlier conclusion that the ferrite grain size is important but does not fully explain the brittle behavior of steel. A detailed study of preyield phenomena at low temperatures has shown that the generally accepted dislocation pile-up theory of cleavage fracture does not explain, by a factor of more than 1000, the local strain prior to fracture. Furthermore, careful examination of both flat and cylindrical specimens has revealed numerous microcracks formed just prior to fracture at low temperatures. Under certain conditions, several of these microcracks can join up to form a single larger crack (Fig. 3).

Ship Structure Committee experience of recent years has demonstrated that the most productive brittle-fracture studies have been those that most closely investigated fundamental mechanisms through simplified tests at very low temperatures, at very slow loading speeds or involving specimens of the simplest type. Except for accidental revelation of new insight, the present high degree of understanding of *what* happens prior to and during fracture, as obtained through extensive and large-scale testing, cannot be expected to add appreciably to the understanding of *why* a material behaves as it does.

How Important Are Flaws?

All known ship fractures, and most nonship brittle fractures of structures, originated at a flaw, void or structural discontinuity. The severity of structural discontinuity can be controlled by proper design. The size, severity and frequency of flaws can be partially controlled by proper procedures in the steel mill and during welding. But until the influence of a flaw on fracture initiation is better understood, it will not be possible to specify precisely how large and severe a flaw must be to warrant replacement of that portion of the structure.

Although quantitative evaluation of flaws is yet to be achieved, one important experimental observation has emerged from studies of flaw behavior; the magnitude and pattern of residual stresses in the region of a flaw, as well as the shape and size of the flaw, can profoundly affect the performance of a structure. The combined influences of better understanding of fracture mechanics and improved residual-stress measurement should bring closer the goal of precise evaluation of flaw severity. In this field there is clear need for fundamental studies rather than direct empirical work.

Flaw-detection methods are better developed today than are the flaw-evaluation criteria. A combination of fundamental and empirical studies has produced heartening progress over the last few years. The flaw-detection research program has been comprehensive in its studies of radiological methods. Tests have been completed for a handbook on the use of available gamma-ray sources for ship-hull inspection. New methods are being studied for detection of flaws through use of a quantitative radiation counter instead of the usual photographic film. Recent work indicates it may be possible, through X-ray scattering techniques, to inspect ship hulls with all men and equipment on only one side of the plate. A complete survey of the ASTM standard weld-flaw

Fig. 3 Assembly of connected microcracks that form an incomplete fracture in a steel specimen at —196° C. X 1000. (Owen, Averbach and Cohen, SSC-109.) (Reduced by 1/3 upon reproduction)

specimens by ultrasonic means is currently under way as part of a program to investigate all possible methods for improving the speed and accuracy of flaw detection. Other recently developed techniques—graphic and numerical—are planned for later inclusion in this program.

Making Better Steel

One of the most effective early solutions to the brittle-fracture problem in ships was the specification of certain grades of steel by the classification societies. Together with improvements in design and fabrication, the use of better grades of steel has reduced the ship-casualty rate to almost zero. Although the ship-fracture problem has thus been brought under control for the present, one critical new problem and one important region for improvement in steelmaking still demand attention from research groups. The new problem is to improve notch toughness of steel of the increased thickness that results from design of today's much larger merchant vessels, particularly tankers. The needed improvement in steelmaking is the replacement of fully killed steel with a cheaper steel requiring less elaborate manufacturing facilities. The current efforts of the materials-improvement phase of the Ship Structure Committee research program are directed toward practical solutions to these two questions.

Fundamental studies of the brittle-fracture mechanism that should provide greater confidence in the properties of thicker steels have been described above. Pending such better understanding, shipbuilders will continue to avoid very thick plating in large ships through use of double plating or additional internal structural support. Because these expedients present additional fabrication problems and are usually more expensive, the Committee on Ship Steel has recommended a study to determine what is the best possible killed steel for thick plate, including composition, practice and heat-treating variables. An improved killed steel may be able to fulfill temporarily the requirements for thick steel of high quality until the fracture behavior of thick plate is better understood and the most suitable material can be selected.

In an effort to produce experimental semikilled steels that would be acceptable alternatives to the fully killed steels now in use in thicknesses over one inch, trial heats were made that proved to be as good as the present steels in thicknesses to 1¾ in. (Fig. 4). Preliminary results of tests in progress on three full-scale production heats of this high-manganese low-carbon semikilled steel appear to verify the conclusions from the experimental heats.

The growing use of controlled-temperature mill rolling of steel plate in a number of countries abroad has been followed with considerable interest by investigators in this country, even though it is doubtful whether American mills could at present tolerate the reduction in capacity that would result from controlled cooling of slabs during the rolling process. Several controlled-rolled plates have been obtained from one European steel producer by the Ship Structure Committee for study. A careful examination of the gross and fine structure of these plates may reveal, in conjunction with other parallel studies in brittle fracture, some of the factors that determine the reported improvement in quality. If the improvement from controlled rolling can be satisfactorily related to service behavior, this mill practice will provide manufacturers and users with an additional alternative to fully killed steel for some applications.

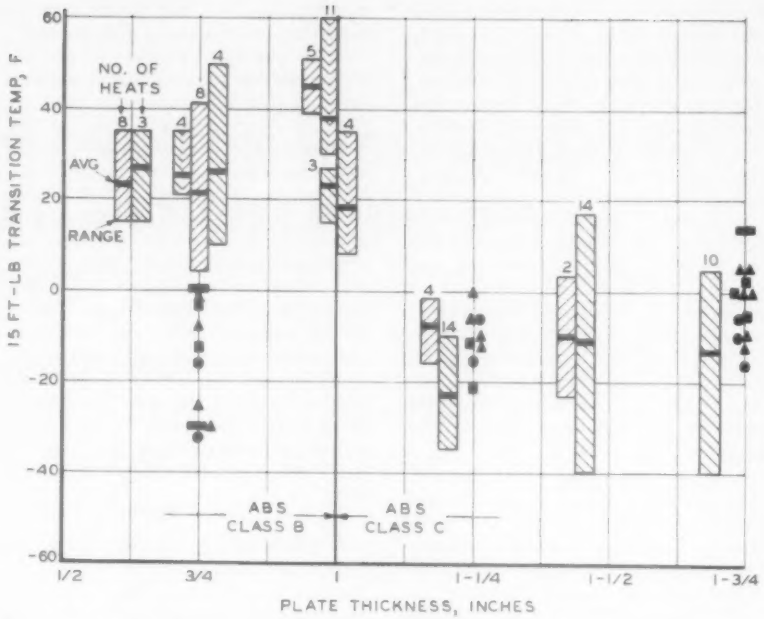

Fig. 4 V-Notch Charpy 15 ft-lb transition temperatures of experimental heats of high-manganese low-carbon semikilled steel (shown as individual points of various shapes, as reported by several laboratories) as compared with American Bureau of Shipping classes of steels in the same thickness ranges (shown cross-hatched). (Vanderbeck, SSC-101)

The quality of currently produced steel must be known accurately in order to evaluate the effectiveness of any proposed change in steelmaking practice. One project, conducted jointly with the American Iron and Steel Institute, has developed simplified mill sampling methods based on a thorough study of a small number of heats of semikilled and killed ship steel from several commercial mills. Tentative conclusions indicate that two or three samples from different locations within a single ingot can provide a measure of the average values and range of values for an entire heat. This sampling procedure is now being used on a number of commercial heats to determine the range of properties within a heat and among several heats. Another testing program has studied steel samples obtained directly from shipyards to find out whether current steel going into ships is better than the old wartime steel. No recent data have contradicted earlier conclusions that current steel used in ship construction is markedly better, with an average transition temperature 43° F below the average of samples taken from wartime fractured ships.

Designing Better Ships

Within recent years improved understanding of the nature of ocean waves has provided hope for ultimate fulfillment of the designer's dream of knowing all loads acting on a ship. If development of knowledge of the load system were accompanied by corresponding refinements in design procedures, the stress pattern throughout the ship could be calculated. Then the ship designer could utilize materials of known properties with much greater confidence and thus could surely improve the design of a ship and effect savings in weight of structural material. The final product of this long-term research program would be a safer ship, cheaper to build and capable of carrying a greater payload.

Research in several fields will be able

to contribute to these improvements in ship design. Until recently the fields of oceanography and structural design, for example, had nothing in common, but soon the work of the investigator studying shape and frequency distribution of waves will vitally affect the design loads used by the ship designer. In an effort to relate such diverse research efforts, the Society of Naval Architects and Marine Engineers and the Ship Structure Committee are jointly sponsoring preparation of a monograph describing the current state of knowledge on waves, ship response to waves and the resultant forces on and stresses in a ship. This report will provide a basis for planning research programs in the fields that most require attention.

A group under the Committee on Ship Structural Design is already preparing recommendations for a comprehensive long-range research program that can be used as a guide for future studies directed toward achieving rational design of ships. In this study the investigators are utilizing the monograph mentioned above and other pertinent literature. A second group is preparing a report of current methods of structural analysis and design in other fields that may be useful in ship design.

These planning projects will provide the foundation for a long-term research program that will require the joint efforts of many groups. Much of the work of the first few years will be fundamental in nature to develop sound bases for understanding and predicting phenomena such as ocean waves, thermal stresses in structures and the influence of inelastic deformations. These studies will not all bear fruit immediately in the form of improved ship design. Many of the research results will contribute only indirectly by providing facts upon which further research of a more applied nature will depend. Out of the latter work should come, in stages, the ship hull improvements that are the goal of the combined research programs.

Acknowledgment

A description of the Ship Structure Committee research program would be incomplete without at least a list of the research organizations and people who have been or are actually performing the work. Those groups connected through recent or current research contracts with the Ship Structure program described herein are as follows:

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University of Illinois—Prof. W. J. Hall, Prof. R. J. Mosborg, Prof. W. H. Munse, Prof. N. M. Newmark
Massachusetts Institute of Technology—Prof. B. L. Averbach, Prof. W. A. Backofen, Prof. Morris Cohen, Dr. W. S. Owen
National Bureau of Standards—J. A. Bennett, C. L. Staugaitis, Dr. M. L. Williams, Dr. W. J. Youden
Naval Ordnance Laboratory—E. L. Criscuolo
Naval Ordnance Test Station—Dr. J. I. Bujes
Naval Research Laboratory—Dr. J. M. Krafft, W. S. Pellini, P. P. Puzak
New York Naval Shipyard—E. A. Imbembo, N. A. Kahn*
New York University—Prof. George Gerard
Southwest Research Institute—Dr. Edward Wenk, Jr.
Stevens Institute of Technology—Prof. B. V. Korvin-Kroukovsky, Prof. E. V. Lewis
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(*Continued on page 288-s*)

CHLORINE ADDITIONS FOR HIGH-QUALITY INERT-GAS METAL-ARC WELDING OF ALUMINUM ALLOYS

Chlorine additives permit radiographically sound inert-gas metal-arc welds to be made in Al-Mg alloys despite the presence of contamination on the filler wire which tends to form porosity and dross. Possibility of substantial reduction in welding cost is indicated

BY M. B. KASEN AND A. R. PFLUGER

ABSTRACT. Contamination on the surface of aluminum filler wire is often the cause of poor quality inert-gas metal-arc welds. This paper deals with additions of chlorine to the arc area to eliminate unsoundness due to such contamination. It covers multipass flat-position welds using Al-Mg plate and filler wire.

A study was made in which the liberation of contamination from the filler-wire surface was simulated by addition of hydrogen, propane, water vapor or oxygen to the arc area through the contact tube of the welding torch. The quantity of each of the contaminating agents necessary to produce a weld of very poor quality was determined. Chlorine added to the arc area in the range of 3 to 20 cu cm/min was found to counteract effectively the deleterious effects of each of these contaminators. Further tests with purposely contaminated filler wires resulted in an equally marked benefit. A small quantity of chlorine permitted radiographically sound welds to be made with mill-run wire and with wire contaminated by a hydrated oxide. Indications were obtained that chlorine additions can also overcome the effect of contamination which naturally occur on commercial welding wire of the Al-Mg type, thus providing insurance against unsound welds resulting from wire which has been improperly cleaned or which has become recontaminated during storage or use.

A chlorine flow of 10 cu cm/min added to the arc area through the contact tube of the welding torch is suggested as optimum. Recommendations are given on methods to obtain this flow rate and on measures which must be taken to overcome corrosion problems created by the chlorine. It is concluded that welding with the minute quantities of chlorine described in this paper can be safely undertaken in any welding area adequately ventilated for normal welding.

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The use of chlorine as described in this paper is protected by patent rights of the Kaiser Aluminum & Chemical Corp.

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Introduction

Heavy aluminum sections can be joined at a faster rate with the inert-gas metal-arc welding process than with any other process commercially available. This, combined with freedom from postweld cleaning, has made inert-gas metal-arc welding very popular with fabricators.

The inert-gas metal-arc process is capable of producing welds of excellent quality in a variety of aluminum alloys when the welding equipment is properly functioning and when the base metal and filler metal are clean. However, despite all reasonable precautions, welds made under shop and field conditions frequently contain porosity and dross in excess of code limitations.

The conventional static mechanical properties of welds are relatively unaffected by small amounts of porosity but fall sharply as the level of porosity increases. Figure 1 indicates the general relationship between porosity and mechanical properties of welds in a typical Al-Mg alloy. The mechanical properties are also affected by dross in the weld metal. The presence of dross is reflected primarily in lower elongation values and in the inability of welds to pass transverse bend tests.

Most of the porosity and dross found in a weld results from contamination on the filler wire surface. The high ratio of wire surface area to the volume of deposited metal will introduce a large concentration of contamination into the weld despite a relatively low concentration of contamination per unit area of wire surface.

Porosity and dross may also result from poorly cleaned base metal or may be introduced into the weld through the use of impure shielding gas.

Finally, weld defects of this type may result from contamination of the shielding gas with the surrounding air. This often occurs when the inert-gas shield is momentarily disrupted due to arc fluctuation.

Simple cleaning procedures prior to welding can eliminate the plate as a source of contamination. The high standards of purity being maintained by the producers of inert shielding gases have largely eliminated this source of unsoundness in aluminum-alloy welds. Likewise, improvements in the power sources and in the inert-gas metal-arc welding equipment have done much to eliminate unsoundness arising from arc instability.

Commercial production of filler wire free of surface contamination has been a more difficult problem. The economics of manufacturing require that the wire be cleaned and spooled at a very rapid rate, yet cleaning treatments require time to be effective. Thus, a balance between quality and cost of manufacture has to be established by each fabricator of welding wire. That high-quality inert-gas metal-arc welding wire is at present commercially available in a variety of alloys and sizes is a tribute to the efforts of manufacturers to overcome this problem.

Thus it would seem that the problem of contamination has been solved, although at a considerable increase in the cost of the welding operation. Why, then, do fabricators continue to be troubled with porous and drossy welds?

This can be attributed primarily to recontamination of the filler wire during storage or while in use.

This paper presents the results of a study to devise a method of counteracting the deleterious effects of contaminators during the welding operation itself, thus rendering the condition of the wire surface less critical. The objectives were two-fold: first, to provide a method of welding which would insure consistent production of high-quality welds, and second, to reduce the cost of welding by rendering expensive wire-cleaning processes unnecessary. The study was limited to the Al-Mg alloys.

The effect of chlorine addition during inert-gas metal-arc welding was first observed in a weld made with an Al-Mg filler wire which had been known to produce welds of poor quality. Introduction of a small amount of chlorine into the argon shielding-gas stream during the welding operation was found to cause a significant improvement in the quality of the weld as determined by radiography.

Subsequent tests, with and without chlorine in the shielding gas, repeatedly demonstrated that chlorine additives were effective in reducing the level of both porosity and dross in inert-gas metal-arc welds. As a result, a significant improvement in static mechanical properties was observed.[1]

Unfortunately, further experiments with a wider selection of filler wire indicated that, while chlorine additions to the shielding gas improved the quality, some porosity remained in the welds. Variation in the chlorine content, in rate of shielding-gas flow and in arc length were studied without providing the answer to complete porosity removal.

Substantial improvement in the effectiveness of chlorine addition was achieved when an automatic inert-gas metal-arc welding torch was modified to permit the addition to be made through the contact tube. Thus, by introducing chlorine directly into the arc area, its effectiveness was greatly increased and the improvement in weld quality became consistent.

It was realized at the inception of this study that accurate assessment of the effectiveness of the chlorine additive would be almost entirely dependent upon precise knowledge of control weld quality, i.e., the quality that would result in the absence of chlorine. It soon became apparent that naturally contaminated wire was inadequate for control purposes because of variation in the amount and type of contamination. Furthermore, a determination of the precise type and quantity of contamination on the wire surface posed formidable technical problems. A better system of control was therefore required.

Control of weld quality was finally achieved by introducing known quantities of specific contaminating agents directly into the arc area while welding with a filler wire of excellent quality. Thus, any desired level of weld quality could be produced and duplicated with knowledge of both the type and quantity of the contaminating agent.

Solution of the problems of effective chlorine addition and establishment of precise control over porosity and dross forming contamination permitted the following work to be accomplished.

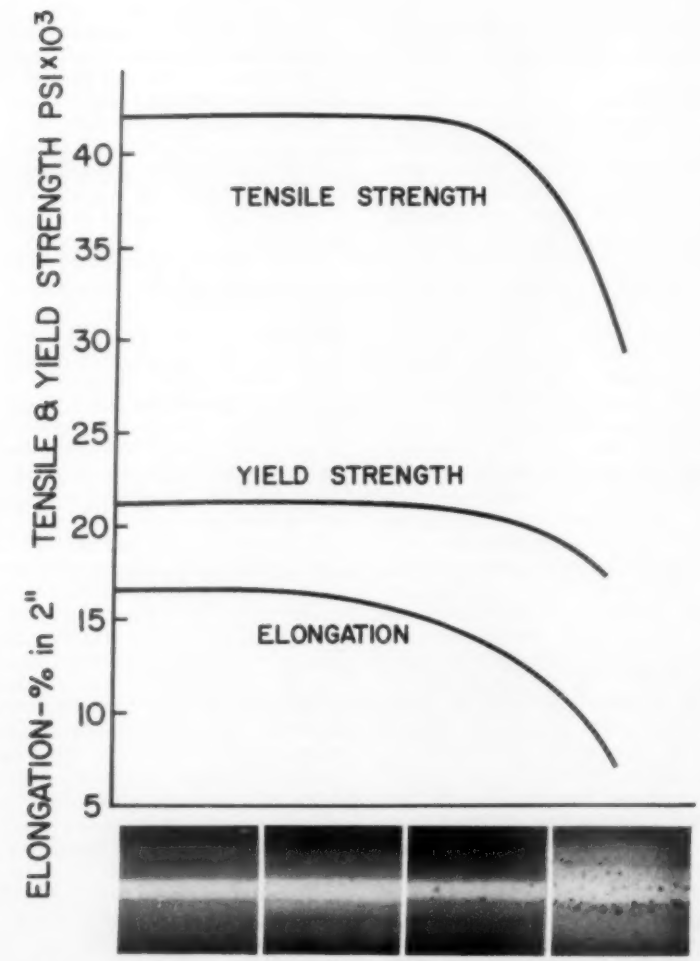


Fig. 1 General relationship between porosity and mechanical properties of welds

Effect of Chlorine on Welds Made with Specific Contaminating Agents

Experimental Procedure

Hydrogen, propane, water vapor and oxygen were introduced into the arc area to simulate the presence of hydrated oxides and hydrocarbons on the filler-wire surface. A similar technique has previously been used by other investigators to simulate contamination of the shielding gas.[2, 3]

In the present study the contaminating agents were introduced into the arc area through the contact tube of an automatic inert-gas metal-arc welding torch, thus closely simulating the liberation of contamination from the surface of a contaminated filler wire. This was accomplished through modification of the welding torch as shown in Figures 2 and 3. Two diametrically opposite holes were drilled into the upper portion of the welding torch and copper tubes were brazed in place. The desired contaminating agent was introduced through one copper tube while the chlorine was introduced through the other. The additives then passed through the oversized liner, through the contact tube and into the arc area. A snug collar was provided between the flexible conduit and the torch. This collar reduced escape of the gases back toward the drive rolls without interfering with passage of the filler wire.

Accurate determination of minute quantities of both the contaminator

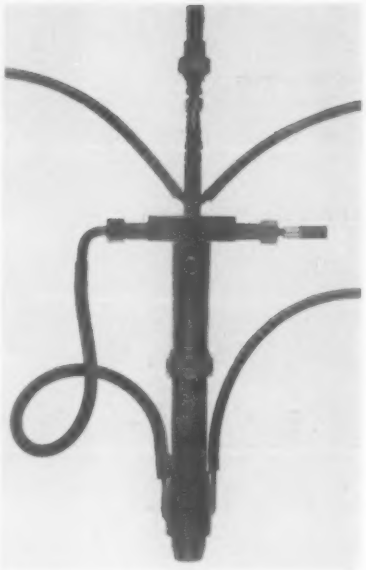


Fig. 2 Automatic inert-gas metal-arc welding torch adapted for simultaneous introduction of two additives to the arc area

and of chlorine passing through the contact tube was required. This was accomplished by metering known mixtures of argon plus the additive whenever the amount of the additive was so low as to cause metering problems. Thus, hydrogen was added as a 5% mixture, propane as a 1% mixture and chlorine either as a 3% or a 0.5% mixture by volume. A simple calculation yielded the quantity of these additives at any flow rate. The much larger quantity of oxygen used in the study permitted metering of the pure gas.

The water-vapor addition was controlled by passing various quantities of moist argon into the arc area. Control over moisture content was achieved by passing the argon through an ice-water mixture before introducing it into the arc area. Measurement of the resulting dew point permitted the quantity of moisture entering the arc area to be determined for any flow rate.

The flow rates of the additives were metered at the exit end of the contact tube with the filler wire in place. One of several metering systems was used, depending on the flow rate. Very low flows were either measured directly with a wet test meter or by a manometer measurement of the pressure drop across a controlled orifice. Precision flowmeters were used for controlling the larger flows. All metering equipment was calibrated with a wet test meter having an accuracy of $\pm 1/2\%$. The quantity of hydrogen, propane, oxygen and chlorine added to the arc area is reported in cubic centimeters per minute (cu cm/min). The quantity of water vapor is reported in grams per minute (g/min) of moisture entering the arc area.

Table 1—Standard Chemical Compositions of 5083 Plate Alloy and 5183 Filler Wire

Chemical composition, %	*Alloy 5083*	*Alloy 5183*
Silicon, max	0.40	0.40
Iron, max	0.40	0.40
Copper, max	0.10	0.10
Manganese	0.50–1.0	0.50–1.0
Magnesium	4.0–4.9	4.3–5.2
Chromium, max	0.25	0.25
Zinc, max	0.25	0.25
Titanium, max	0.15	0.15
Balance	Al	Al*

* Beryllium, 0.0005% maximum.

The base metal used throughout the study was 3/8-in. thick 5083 aluminum alloy. The filler wire was 5183 aluminum alloy of 3/32 in. diam. The standard chemical compositions of these two alloys appear in Table 1.

A rectifier power source with a rising volt-ampere characteristic was used throughout the program. All welding was automatic with stationary torch and moving workpiece. A 60-deg V-groove joint design was used and the welds were completed in either three or four passes. All welds were made in the flat position with an argon outer shielding gas flow of 60 cfh.

The base metal was cleaned by caustic etching followed by a nitric-acid rinse. Wire brushing between weld passes constituted the only additional cleaning.

All filler wire used in this portion of the investigation was required to pass stringent weld-quality tests. Only wire capable of producing radiographically clear multiple-pass welds under normal conditions was accepted.

The quantity of each specific contaminating agent necessary to produce a weld of very poor quality was determined by making a series of welds with varying amounts of the contaminator added to the arc area. The series produced with the hydrogen additive is illustrated in Fig. 4; similar series were run with propane, water vapor and oxygen. Radiography was used for evaluation of welds made with the porosity-forming

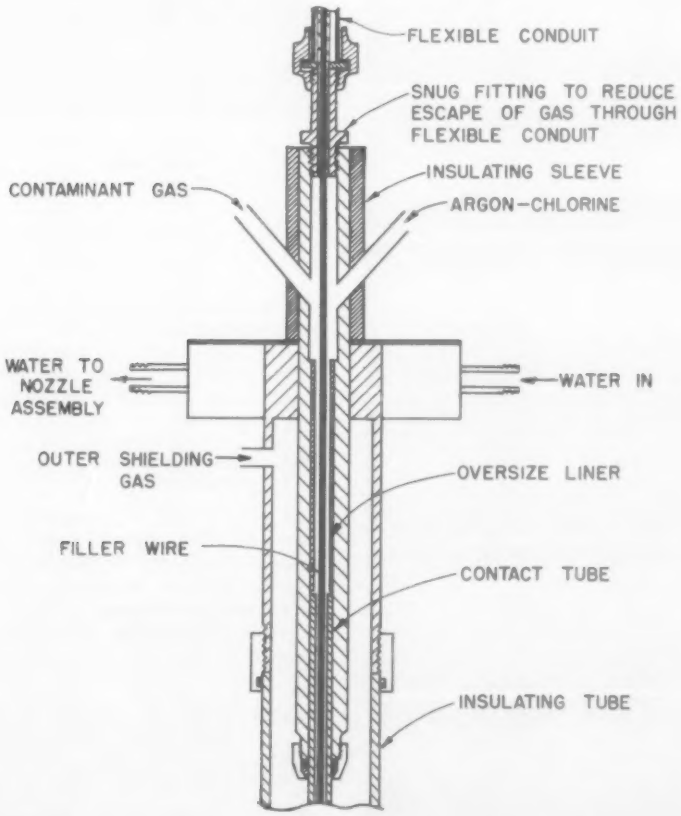


Fig. 3 Sketch of internal modification of the upper portion of an automatic inert-gas metal-arc welding torch to permit introduction of additives through the contact tube

contaminators (hydrogen, propane and water vapor). The effect of oxygen was evaluated by fracture examination since it produced dross not easily detected by radiography.

The quantity of each contaminating agent necessary to produce a weld of very poor quality was found to be as follows:

Hydrogen	8.5 cu cm/min
Propane	1.3 cu cm/min
Water vapor	1.4 g/min
Oxygen	210 cu cm/min

The weld quality achieved with these amounts of hydrogen, propane, water vapor and oxygen are illustrated in the control welds, Figs. 5*a*, 6*a*, 7*a* and 8*a*, respectively.

A series of 13 welds was then made in each contaminator series with the above control level of contaminator present in each weld and with chlorine flows of either 0.5, 1.5, 3.0, 10 or 20 cu cm/min. These flows were at random throughout the series to minimize the effect of experimental error. Each series also included three welds with no chlorine addition. The resulting welds were evaluated either by radiography or by examination of fractures as noted above.

Experimental Results

The deleterious effect of each of the contaminating agents studied was completely counteracted by additions of 20, 10 or 3 cu cm/min of chlorine to the arc area during welding (Figs. 5, 6, 7 and 8). The scavenging effect of chlorine generally was less at lower flow rates, and the results became somewhat erratic. For example, a flow of 1.5 cu cm/min of chlorine almost completely overcame the effect of propane contamination, yet the same quantity of chlorine only partially overcame the effects of hydrogen, water vapor and oxygen. At the lowest chlorine addition (0.5 cu cm/min), the quality of the resulting welds began to approach those of the controls except for the oxygen series (shown in Fig. 8) which still showed a remarkable reduction in dross level.

Effect of Chlorine on Welds Made with Purposely Contaminated Filler Wire

The above tests had conclusively shown that chlorine addition could overcome the deleterious effects of various gaseous contaminators in the arc area. The process was then carried one step closer to practical conditions by a study of the effect of chlorine additives on the quality of multipass flat-position inert-gas metal-arc welds made with purposely contaminated filler wire.

Two filler wires, both of 5356 aluminum alloy, were used in this study. A hydrated oxide was produced on one wire by heating it in steam. The other wire was used in the as-drawn condi-

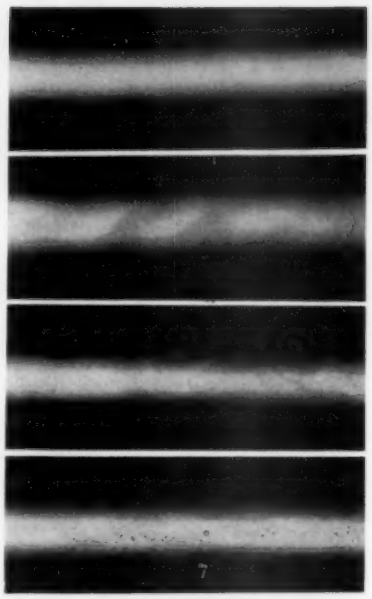


Fig. 4 Radiographs illustrating the interrelationship between weld porosity level and hydrogen content

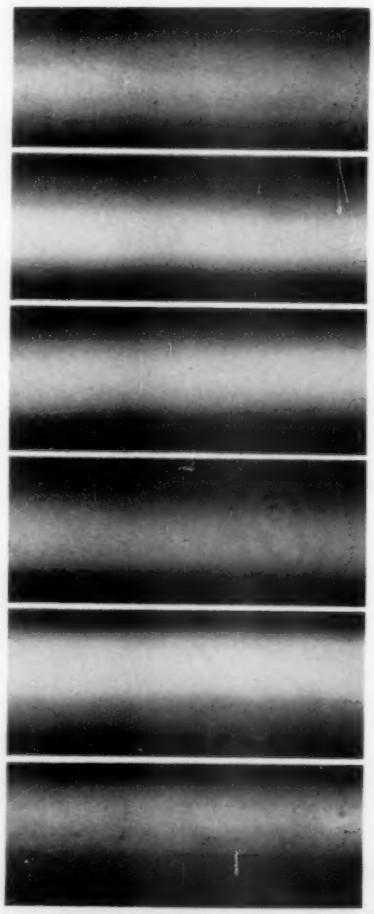

(a) Control weld
8.7 cu cm/min hydrogen
No chlorine
(b) 8.7 cu cm/min hydrogen
20 cu cm/min chlorine
(c) 8.7 cu cm/min hydrogen
10 cu cm/min chlorine
(d) 8.7 cu cm/min hydrogen
3 cu cm/min chlorine
(e) 8.7 cu cm/min hydrogen
1.5 cu cm/min chlorine
(f) 8.7 cu cm/min hydrogen
0.5 cu cm/min chlorine

Fig. 5 Radiographs showing effectiveness of chlorine additive on hydrogen contamination

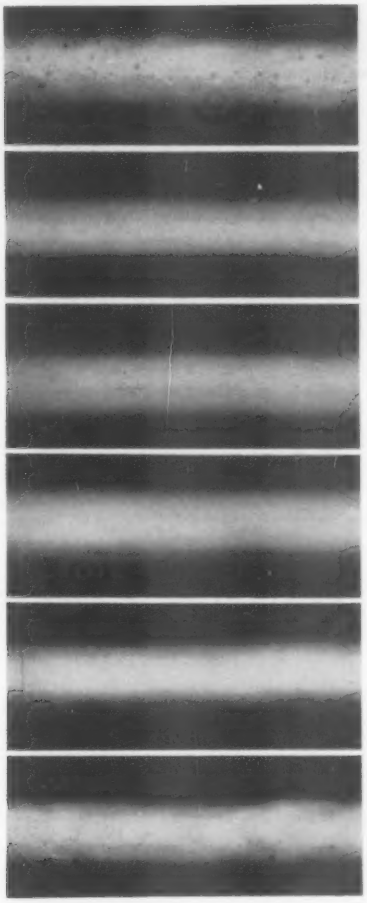

(a) Control weld
1.3 cu cm/min propane
No chlorine
(b) 1.3 cu cm/min propane
20 cu cm/min chlorine
(c) 1.3 cu cm/min propane
10 cu cm/min chlorine
(d) 1.3 cu cm/min propane
3 cu cm/min chlorine
(e) 1.3 cu cm/min propane
1.5 cu cm/min chlorine
(f) 1.3 cu cm/min propane
0.5 cu cm/min chlorine

Fig. 6 Radiographs showing effectiveness of chlorine additive on propane contamination

tion, i.e., with the normal amount of residual drawing lubricant on the wire surface.

The radiographs of Fig. 9 show the marked benefit due to a chlorine additive of 20 cu cm/min when welding with the filler wire contaminated with hydrated oxide. The deleterious effect of this oxide was completely counteracted by the chlorine addition and a radiographically clear weld was produced.

The radiographs of Fig. 10 show the equally marked benefit resulting from addition of chlorine when welding with the filler wire in the as-drawn condition. Again, the effect of the contamination was completely overcome and a radiographically clear weld was produced.

Effect of Chlorine on Welds Made with Commercial Filler Wire

As mentioned in the introduction to this paper, clean filler wire may become contaminated during storage. As a result, fabricators continue to be troubled with weld unsoundness attributable to poor wire-surface quality.

The success of chlorine additives with both gaseous contaminators and purposely contaminated filler wires indicated that additions of chlorine to the arc area should also be successful in overcoming the deleterious effect of contamination occurring naturally on the wire.

The testing of a large number of welds, with and without addition of chlorine to the arc area, is required to establish firmly the effect of chlorine on the quality of welds made with commercial wire. However, the following limited test series does provide an indication of the effectiveness.

Thirteen spools of $^{3}/_{32}$-in. diam inert-gas metal-arc filler wire of the Al-Mg type were evaluated with and without chlorine addition to the arc area. These wires were representative of the commercial production of three major suppliers. The wires, of unknown quality, had been held up to three years in dry storage.

A conventional argon weld and a weld with chlorine addition were made consecutively in $^{1}/_{2}$-in. plate for each spool of wire. Two layers of wire were removed from each spool before welding to eliminate the variable quality often found in surface layers of wire. All welds were multipass in the flat position. Evaluation was by radiography.

All 13 welds made with chlorine additive were found to be radiographically clear. Three of the 13 conventional welds contained porosity to an extent approaching that of the control welds in the gaseous contaminator series. The remaining conventional welds were of excellent quality.

Discussion of Results

These data indicate that addition of minute quantities of chlorine to the arc area during inert-gas metal-arc welding will effectively counteract hydrogen, propane, water vapor and oxygen when each contaminator is present in the arc area in sufficient quantity to affect the quality of the welds seriously. Furthermore, the data indicate that chlorine additions are effective in counteracting the deleterious effects of contamination on the filler-wire surface. Thus far, data have not been accumulated on the effectiveness of chlorine addition when welding with alloys other than the Al-Mg type, nor has the effectiveness of the addition been fully evaluated in out-of-position welding.

The results of the study hold a twofold significance. First, the use of chlorine additives provides the fabricator with a means of insuring the quality of flat-position welds in Al-Mg alloys. Secondly, the data indicate that the use of chlorine can obviate expensive wire cleaning processes while maintaining weld quality, thus effecting a significant reduction in the cost of welding alloys of the Al-Mg type.

The data indicate that a flow rate of from 3 to 20 cu cm/min of chlorine is required for best results. A flow rate of 10 cu cm/min is recommended. This is most conveniently achieved through use of an argon-chlorine mixture containing from 1 to 3% of chlorine by volume. Metering becomes difficult at higher chlorine percentages while an excessively high flow rate of the mixture is required if the chlorine content is very low. The 97% argon – 3% chlorine mixture has been found to be very satisfactory. The recommended chlorine additive rate can be obtained with a total flow of 0.5 cfh of this mixture through the contact tube of the welding torch. It is recommended that all chlorine additive mixtures have a dew point below −40°F.

The presence of chlorine in the arc area slightly increases the amount of spatter and also results in a slight loss of magnesium during transfer across the arc. Both these effects were found to be of negligible importance.

It was observed that the presence of chlorine in the arc area reduced the

visible "cleaning action" of the arc to an extent somewhat proportional to the amount of chlorine present. For example, the cleaning action was appreciably reduced at a chlorine flow of 20 cu cm/min while very little reduction was evident at a flow of 0.5 cu cm/min.

Weld beads were slightly narrower when chlorine was present in the arc area than when chlorine was absent. In some cases, this might necessitate a change in pass placement or an increase in the number of passes. Narrowing of the weld bead is probably related to diminishing of visible cleaning action.

Welding with minute quantities of chlorine added to the arc area as described in this paper can be safely accomplished in any welding area adequately ventilated for normal welding. The presence of chlorine is indicated only by a slight odor which welders have not found objectionable. No ill effects have been sustained by any personnel during several years of welding with chlorine additives.

While the mechanism by which chlorine counteracts weld contamination has not been established, experimental evidence indicates that the mechanism described in the following theory accounts for at least a part of the scavenging effect.

The rate at which gas escapes from a weld pool is determined primarily by the rate at which the gas bubbles can rise to the pool surface through the molten weld metal. If the rate is fast enough to permit most of the gas to escape before the pool solidifies, the weld will be of good radiographic quality. The time during which the weld pool is molten is determined by the rate of heat extraction from the weld and by the solidification range of the weld metal. These factors may be considered to be constant for any given set of welding conditions and alloy combination. Consequently, the fluidity of the molten metal is the only variable which could alter the rate at which gas escapes from the pool. The present theory assumes that the presence of dross in the weld pool reduces its fluidity, thereby reducing the rate of escape of the gas and lowering the weld quality. Thus, removal of porosity is contingent upon dross removal.

Argon gas of high purity is used to shield both the arc area and the weld pool during inert-gas metal-arc welding, yet small particles of dross are frequently found in weld metal. Where does this dross originate? How does it get into the weld pool? To answer these questions, some of the characteristics of the filler wire and of metal transfer across the arc must be considered.

The oxide film which naturally develops on aluminum alloys is normally very thin. However, improper fabricating practices or poor storage conditions frequently cause a heavy oxide coating to develop on the wire. This heavy oxide coating obviously constitutes one source of dross in the weld metal. Moreover, this oxide could adsorb moisture or gases and it could contain water of hydration, all of which would contribute to dross formation in a weld.

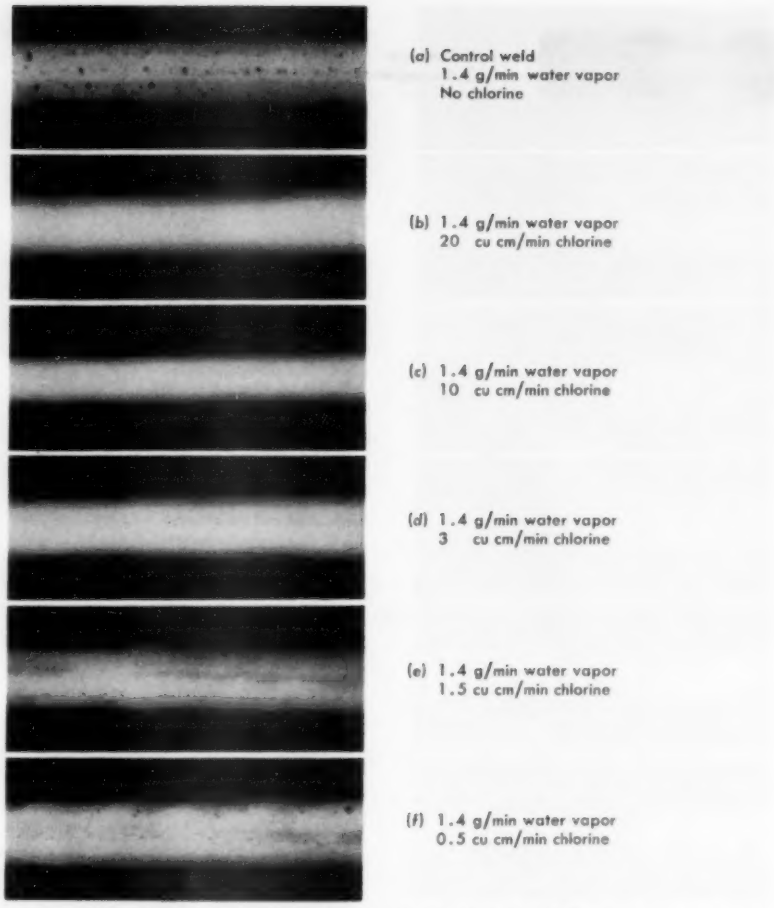
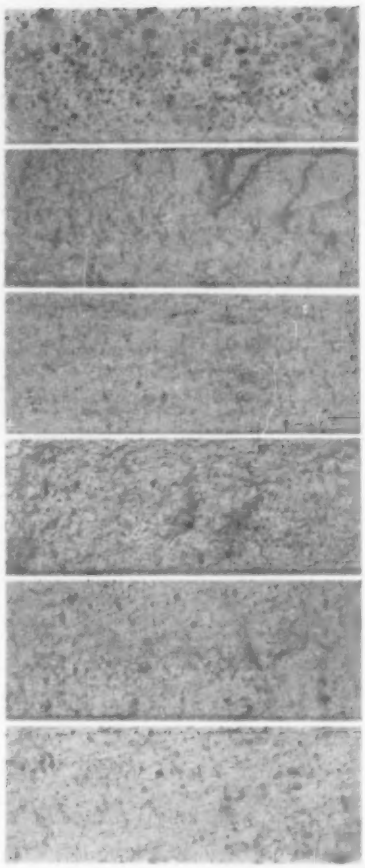

(a) Control weld
1.4 g/min water vapor
No chlorine
(b) 1.4 g/min water vapor
20 cu cm/min chlorine
(c) 1.4 g/min water vapor
10 cu cm/min chlorine
(d) 1.4 g/min water vapor
3 cu cm/min chlorine
(e) 1.4 g/min water vapor
1.5 cu cm/min chlorine
(f) 1.4 g/min water vapor
0.5 cu cm/min chlorine

Fig. 7 Radiographs showing effectiveness of chlorine additive on water vapor contamination

Experience has shown that welds made with alloys containing relatively large quantities of magnesium are generally less sound than welds made with alloys of similar freezing range but which contain little or no magnesium. It is known that magnesium-containing alloys have a greater tendency to form and entrain dross and gas bubbles during casting. This is attributed primarily to the high reactivity of the magnesium. It is considered likely that this reactivity causes formation of submicroscopic oxide films on the surface of the metal droplets during transfer across the arc column during welding. The oxygen for this reaction is believed to originate primarily from the filler-wire surface as explained above and possibly from air introduced through the contact tube. The oxide films thus formed would be carried into the weld pool by the molten droplets.

Dross could also be introduced into the weld pool as a result of oxidation of metal vapor in the arc area. It is believed that a large portion of the metal vapor in the arc area results from vaporization of metal from the droplets as they traverse the arc. It is further believed that the higher vapor pressure of magnesium as compared to aluminum undoubtedly increases the amount of metal vapor in the arc area when welding with Al-Mg alloys. This vapor may readily combine with any oxygen present in the arc area to form magnesium oxide which would be driven into the weld pool by the force of the arc.

It is possible that chlorine present in the arc area acts to break up any oxide film already formed. This reduces the possibility of the oxide forming continuous films in the weld pool. As a result, the fluidity of the weld pool is increased, with consequent improvement in weld quality.



(a) Control weld
210 cu cm/min oxygen
No chlorine

(b) 210 cu cm/min oxygen
20 cu cm/min chlorine

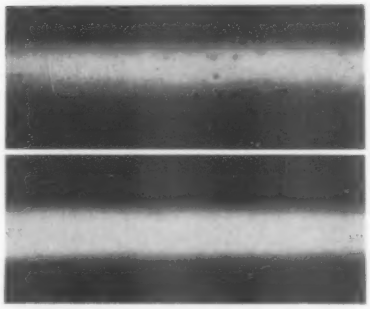
(c) 210 cu cm/min oxygen
10 cu cm/min chlorine

(d) 210 cu cm/min oxygen
3 cu cm/min chlorine

(e) 210 cu cm/min oxygen
1.5 cu cm/min chlorine

(f) 210 cu cm/min oxygen
0.5 cu cm/min chlorine

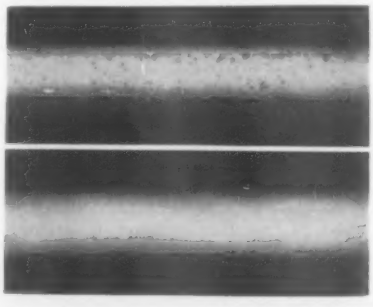
Fig. 8 Weld fractures showing effectiveness of chlorine additive on oxygen contamination. (Black spots on fracture denote dross)



(a) Conventional argon weld, no chlorine used

(b) Argon plus 20 cu cm/min of chlorine added to the arc area

Fig. 9 Radiographs showing the effectiveness of chlorine additive when using a welding wire coated with hydrated oxide



(a) Conventional argon weld, no chlorine used

(b) Argon plus 20 cu cm/min of chlorine added to the arc area

Fig. 10 Radiographs showing the effectiveness of chlorine additive when using a welding wire contaminated with drawing lubricant (i.e., as-drawn)

It is assumed that some oxide enters the weld pool despite the presence of chlorine in the arc area. Also, it is assumed that some chlorine is introduced into the weld pool by the action of the arc. This chlorine can then act as a fluxing agent upon oxide films and dross, bringing them to the metal surface and increasing the fluidity of the pool. This facilitates release of gas and dross and is reflected in improved weld quality. It is also possible that chlorine fluxes the surface of the weld pool to facilitate the escape of gas, dross and other contamination from the molten metal.

The reactions proposed in the above theory should cause a dross film to appear on the surface of the weld bead. Such dross films, evidenced by a darkening of the weld bead, are a characteristic of welds made with chlorine additives.

Other theories have also been suggested in which the scavenging action is attributed to ionization of gas in the arc column or in which a chemical reaction of a different type is hypothesized. The authors will welcome discussion on this subject from interested parties.

Mechanical Properties of Welds Made with Chlorine Additions

As mentioned in the introduction, the addition of chlorine to the shielding gas had been found to result in a significant improvement in static mechanical properties as well as in a distinct improvement in weld soundness. For example, the average transverse tensile strength of one group of welds was increased from 39,700 psi to 43,300 psi, reflecting the improvement in quality due to chlorine addition. The average elongation values obtained from the same group of welds increased from 12.4 to 17.9%. The improvement in quality obtained by addition of chlorine through the contact tube, as described in this paper, may be expected to result in a similar increase in weld properties. The statistical significance of such an increase can only be determined after data have been accumulated on a large number of welds. These data are now being accumulated for presentation in a subsequent paper.

Conclusions

1. A small amount of chlorine introduced into the arc area permits radiographically clear flat-position inert-gas metal-arc welds to be produced in Al-Mg alloys despite the presence of large amounts of gaseous contamination in the arc area.

2. Chlorine is equally effective with hydrogen, propane and water vapor when these materials are present in sufficient quantities to make comparably unsound welds.

3. Chlorine is also effective in removing dross resulting from oxygen

additions to the arc area.

4. With addition of a small amount of chlorine to the arc area, radiographically sound welds may be made with wire contaminated by a hydrated oxide.

5. Results indicate that addition of small amounts of chlorine will overcome the deleterious effects of natural contamination occasionally found on commercial welding wire of the Al-Mg type.

6. By making the filler-wire quality less critical, chlorine additions could possibly lead to a substantial reduction in welding cost.

7. For optimum results chlorine must be added to the arc area through the contact tube of the welding torch.

8. The maximum benefit from chlorine addition can be expected when chlorine is added to the arc area as an argon-chlorine mixture with the flow rate adjusted to introduce chlorine at the rate of 3 cu cm/min or greater. A chlorine additive rate of 10 cu cm/min is suggested as optimum. This is most conveniently achieved by passing 0.5 cfh of a 97% argon – 3% chlorine mixture through the contact tube.

9. Welding with minute quantities of chlorine added to the arc area as described in this paper can be accomplished safely in any welding area adequately ventilated for normal welding.

10. Copper-alloy components of the welding installation must be protected against corrosion by the chlorine.

Acknowledgment

The authors wish to acknowledge the efforts of Kenneth Wills and Allan Dolomont in carrying out the welding required in the present program. Mr. Wills deserves special commendation for devising the method of introducing additives through the torch contact tube. The authors also wish to thank Dr. F. L. Howard for his suggestions on instrumentation.

Acknowledgment is due Stuart St. Denis and Jess L. Casey, who performed much of the welding during the initial study from which the present work developed. The guidance and council of Dr. L. W. Eastwood and L. A. Cook during the initial studies are also acknowledged.

APPENDIX

Small amounts of chlorine will form cuprous and cupric chloride corrosion products in portions of the welding equipment fabricated from copper alloys unless precautions are taken. Protection is required only where the chlorine-containing gas is in contact with the susceptible parts, i.e., in the chlorine additive line and in the adapter and contact tube of the welding torch.

Regulators, fittings and hoses of a type resistant to dry chlorine should be used in the chlorine additive line. These components are available at a reasonable cost. The adapter and contact tube should be nickel plated.

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RESEARCH NEWS

(*Continued from page 248-s*)

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Titanium

Symposium on Titanium (*STP No. 204*). 214 pages, 6 by 9 in. Hard cover. Price $4.75. Published by American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Aside from uranium, probably no metal in the past decade has so captured the interest of the metallurgical industry as titanium. It is a good metal, with a combination of availability, lightness with strength and corrosion resistance that makes it of particular interest to the aeronautical industry. This interest, with support from the Department of Defense, has resulted in phenomenal progress in the commercial and technical development of this relatively new metal of construction.

This symposium brings together 14 papers designed to give good technical information on which to base specifications. These papers pertain primarily to property evaluation. The symposium was originally presented during the 2nd Pacific Area National Meeting, Los Angeles, Calif., and sponsored by Committee B-2 on Non-Ferrous Metals and Alloys. The book is illustrated, and many of the papers contain references.

The contents of the book follow:

"Introduction," Bruce W. Gonser; "Variables Affecting the Thermal Stability of Three Titanium Alloys," F. R. Schwartzberg, N. D. Williams and R. I. Jaffee; "The Effect of Temperature on the Uniform Elongation of Titanium Alloys," F. C. Holden, H. R. Ogden and R. I. Jaffee; "The Effect of Composition and Annealing Treatment on the Thermal Stability of Chromium-Molybdenum Alloys of Titanium," H. R. Ogden, F. C. Holden and R. I. Jaffee; "Elevated-Temperature Properties of the 6 per cent Aluminum, 4 per cent Vanadium Titanium Alloy," W. M. Parris, R. G. Sherman and H. D. Kessler; "Development of Titanium-Base Alloys for Elevated Temperature Application," F. A. Crossley, W. F. Carew and H. D. Kessler; "The Effects of Carbon and Nitrogen Contamination on the Notch Tensile Properties of Titanium," E. P. Klier and N. J. Feola; "A Micro Notched-Bar Impact Test for Titanium Alloys," F. C. Holden, H. R Ogden and R. I. Jaffee; "The Measurement of Elastic Modulus of Titanium Alloys," W. H. Graft and W. Rostoker; "The Corrosion and Ignition of Titanium in Fuming Nitric Acid," John B. Rittenhouse; "Unalloyed Titanium Sheet Is Improving," H. A. Barry and Leo Schapiro; "How Statistical Techniques Helped Achieve Better Uniformity in Unalloyed Titanium," Chester R. Smith; "Properties and Fabrication Characteristics of Wrought Titanium Products," Leston B. Stark; "Development of Standardized Specimen Preparation and Testing Techniques for Unalloyed Titanium Sheet," R. L. Folkman and M. Schussler; and "Determination of Gaseous Elements in Titanium," R. M. Fowler.

REINFORCEMENT OF OPENINGS IN PRESSURE VESSELS

A review of studies in this field during the past quarter century

BY E. O. WATERS

There is nothing original or obscure in the statement that a stressed plate is weakened when material is removed from it, and the statement is true regardless of whether this removal of material constitutes a rivet hole in a structural member, an opening in the hull of a ship or a manhole or nozzle connection in a boiler drum. However, the less obvious fact, namely, that the weakening is not necessarily proportional to the amount of material removed, and cannot be compensated by merely adding equal material close to the opening, has required time for its complete acceptance, and has resulted in much uncorrelated, exploratory testing and a fair amount of theoretical study, the latter almost always based on the well-known plane stress problem of the stress concentration around a circular hole in a stretched plate of infinite length and breadth.

It is the purpose of this paper to give a short account of some of the developments in this field, emphasizing those that have occurred since 1930. The aim has been to review briefly what has been done, without criticism, and to point out the gaps in our present knowledge that the Pressure Vessel Research Committee is attempting to fill. Fatigue tests and tests involving external loads are excluded almost entirely, and for two reasons: first, they have not been carried out on a large scale until quite recently, and second, those who are directing such tests are in a much better position than the present writer to report on this phase of pressure-vessel research.

Early Background

As far back as the year 1894, interestingly enough, C. Bach wrote briefly on "A weak point in many of our steam boilers." Nine years later he reported on an experiment that he performed following a recent boiler explosion. The boiler, of wrought iron construction, failed due to fractures that originated at the edge of an unreinforced manhole opening. To throw light on the subject, two cylindrical cast-iron vessels were built (Fig. 1), 2 ft in diam and 5 ft long, one with no side opening and the other with an elliptical manhole $11^1/_2$ x $14^1/_2$ in., with the major axis parallel to the axis of the vessel.* When tested to destruction, the relative bursting pressures indicated a ratio of strengths of the two vessels of 3.27:1. Bach concluded that the weakening was due to stress concentration at the edge of the manhole, combined with bending stresses induced by the method of securing the cover; he also pointed out that the major axis of the hole should be perpendicular to the axis of the vessel—a fact that seems to have been ignored at the time, though certainly recognized today.[1]

Subsequent to this, considerable work was done and several papers published on the general subject of the design of cylindrical vessels with dished heads, but without special attention to the effect of openings. This situation was altered in 1926, when Siebel and Koerber published the results of an "Investigation of Strain and Deformation in Dished Heads with and without Manholes, Loaded by Internal Pressure."[2] The tests had been performed for the August Thyssen steel mills, and included twenty heads ranging from flat to hemispherical, among which were three semi-ellipsoids with 4:1 diameter-depth ratio and fifteen basket forms with various depths and knuckle radii; all had a diameter of 51 in. and 0.787-in. wall thickness. Nine were full heads, four had an offset manway one quarter of the vessel diameter from the side, and seven had central manways, all but two of which were flued inward according to customary practice; these two were flared out, or "drawn." Observations were taken in the following order: (1) measurement of elastic deformation and determination of the commencement of permanent strain and the permissible loading for (2) and (3); (2) measurement of changes of curvature; (3) strain measurements on the outer surface; (4) measurement of permanent deformation and noting the appearance of flow; (5) measurement of elastic deformation after the preceding permanent set. Displacements of points on the head, normal to the surface, were measured by a set of dial gages adjustably mounted on a rigid yoke that spanned the head; changes of curvature were measured by a special instrument carrying two dial gages and contacting the head at four points in a line. A mechanical strain gage with gage length adjustable from $^3/_4$ to $2^3/_4$ in. was used for direct measurement of strains, and lime wash was applied for the detection of plastic strains.

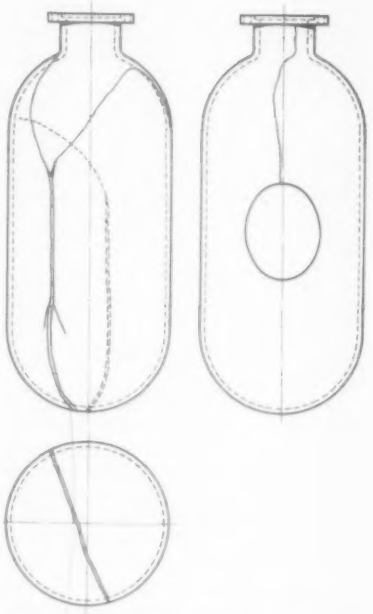

Fig. 1 Bach's cast-iron test vessels

Results are tabulated in the report for the pressures at which permanent deformation took place, maximum elastic displacement and maximum stress

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* Metric dimensions have been converted to their approximate English equivalents throughout this paper.

at 10 atmospheres pressure, and three stress ratios for the actual maximum stress compared with the nominal stress computed for (a) basket heads having the same crown radius, (b) ellipsoidal heads having the same depth, and (c) hemispherical heads having the same semi-diameter. The highest stresses always occurred on the inner surface at the knuckle and the outer surface at the crown or manhole edge. The heads with manholes gave unacceptably high stresses as compared with the full heads, and led the investigators to suggest six means of reducing them: increase the distance between manhole and knuckle, increase the wall thickness throughout the head, increase the wall thickness near the manhole, stiffen up the edge of the manhole, make the manhole more nearly circular, and finally, improve the over-all geometry of the head form near the manhole in accordance with good practice in stress distribution. As an example of the latter, the drawn, or extruded, form was especially recommended, as that would be the natural shape assumed by a membrane under internal pressure. Doubtless there are few who realize that the contoured outlet, now so frequently used for connections of branch lines to manifolds and headers, was advocated at this early date as good geometry for regions of high stress concentration.

In a second investigation reported by these same authors, twelve heads of similar form but greater wall thickness ($1^3/_8$ in.) were given the same tests. It was found that the maximum stresses corresponded in a general way with those of the 0.787-in. wall heads, taking the difference in thickness into consideration, and were affected primarily by the depth of head. Finally, five heads with circular-bored unreinforced openings of various diameters were tested; again, high ring stresses were obtained around the edges of the holes, increasing in amount with the size of the hole, and again the investigators recommended that they be minimized by improving the geometry of the crown, reducing the curvature to zero along the meridians (cone head with basket knuckle) or reversing the curvature to obtain an outward flare.

Theoretical Investigations

A glance at any report of pressure vessel research on openings that mentions theory will convince the reader that the fundamental two-dimensional analysis of an infinite plate with a central hole and a uni-directional load is, almost without exception, relied upon as the starting point for any further development. This analysis, as is well known, is credited to Kirsch who published it in 1898. The reader is also apt to find the statement that the Kirsch solution, while helpful, is quite inadequate except for very small opening-to-vessel diameter ratios. Furthermore, researchers generally agree that the stress-concentration factor 3 of Kirsch's solution, which becomes $2^1/_2$ for the two-dimensional loading in a cylindrical vessel, increases as some function of the ratio of opening diameter to vessel diameter, but the exact form of this function remains elusive. Most theoretical analyses are simply adaptations of Kirsch's solution to fit different geometries, while keeping the analysis strictly within the two-dimensional domain. Much of this work has been done by stress analysts in the field of aircraft design; although they are dealing with large diameter, thin-walled structures, the basic problem of openings reinforcement is the same for them as for the manufacturer of thick-walled vessels for high pressure.

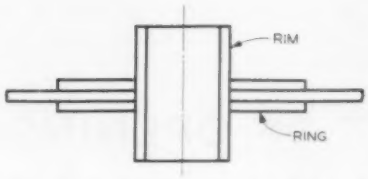

Fig. 2 Beskin's form of reinforced opening

A good example of the foregoing is a paper by Beskin that appeared in 1944.[3] This is a theoretical analysis of an infinite plate with a circular hole reinforced by a so-called "ring" (i.e., a pair of equal circular pads surrounding the hole on both sides of the plate) or by a "rim" (a ring having negligible radial width and no bending stiffness) concentrated at the edge of the hole, or by a combination of ring and rim, as shown in Fig. 2. Although the illustrations and examples in Beskin's paper indicate the use of rims of considerable length (measured normal to the plane of the plate) the analysis is purely two-dimensional and no discount is taken for rim material that is far removed from the plane of the plate. Three conditions of loading are considered: (a) uniform all-around tension on the plate, or "hydrostatic" loading, (b) pure shear at infinity and (c) a combination of (a) and (b) giving uniform tension in one direction. Beskin finds that, with the simplifying assumptions that he makes for the properties of a rim, it is possible to reinforce the plate under hydrostatic loading so as to have a stress index of unity; various configurations will do this, but the one that requires the least amount of reinforcing material is a combination of rim and ring in which the OD of the ring is twice the hole diameter, the combined thickness of plate and ring is 25% greater than that of the plate, and the cross-sectional area of material added in the rim is 75% of that removed in the hole. All reinforcements are balanced in Beskin's derivations, and it should be noted that his stress-concentration factors are computed on the basis of the strain-energy-of-distortion theory of failure, rather than the more usual maximum-normal-stress theory.

This paper has received considerable attention from British investigators, and one finds frequent reference to it in their reports. It contains tables of stress ratios and stress-concentration factors worked out for a great variety of proportions, including rim without ring, ring without rim, and rim and ring combinations consisting of rolled angles with equal legs, all with the three different kinds of loading previously mentioned. The rim-without-ring studies show the detrimental effect of over-reinforcement, i.e., an area of reinforcement equal to 1/(1—Poisson's ratio) multiplied by the area of metal removed gives a stress-concentration factor of unity (under hydrostatic loading) whereas greater areas for the rim give factors greater than unity. In conclusion, Beskin states that, in general, the best reinforcement is obtained with flanges concentrated as closely as possible at the edge of the hole, or with combinations of flanges and thick collars (so-called doubler plates). With a total area of reinforcement of 0.8 × (area of metal removed), stress-concentration factors may be held to 1.3 for hydrostatic loading and 1.5 for unidirectional loading.

A further extension of the hole-in-plate analysis appeared in 1948, in a report by Levy, McPherson and Smith.[4] Like the work of Beskin and that of Gurney, another stress analyst in this field, the derivations are all strictly two-dimensional. Four forms of reinforcing rings, or doubler plates, were investigated, and formulas were derived for the radial and tangential stresses and the radial enlargement, under uniform all-around tension. Two of the rings tapered asymptotically from a thickness of $2t$ at the edge of the hole to t at infinity, according to the formulas $1 + (a/r)^2$ and $1 + (a/r)^4$, where a = hole radius and r = arbitrary radius greater than a; a third ring had a constant thickness of $2t$ and an outside radius of $2a$, with a sharp taper at the outside simulating a fillet weld; the fourth had a shape determined by numerical integration such that the tangential stress was constant at all radii. This so-called "ideal shape" turned out to be a thin ring, much wider (in the direction of the axis of the hole) than the plate thickness, and hence somewhat beyond the limits of two-dimensional theory. Stress concentrations were computed as the ratio of tangential stress at the hole edge to the stress at infinity, elongation ratio as the ratio of hole enlarge-

ment to the increase in size of an equivalent circle in the uncut plate subjected to the same load, and volume ratio as the ratio of reinforcement volume to volume of material removed by cutting the hole. Some tabulated values are as follows:

Type of reinforcement	*Stress index*	*Elongation ratio*	*Volume ratio*
$1 + (a/r)^3$ taper	1.52	2.17	Infinite
$1 + (a/r)^4$ taper	1.65	2.36	1.00
2t constant thickness	1.35	1.93	3.00
Ideal	1.00	1.43	1.89

It is seen that the ideal form is best for stress and elongation, and the steeply tapered form for weight.

This report also includes a theoretical analysis of the stresses and displacements in a plate stretched in one direction only, and reinforced with a doubler plate of arbitrary constant thickness and outside diameter; graphs are given for stress index, and hole enlargement in the direction of pull, vs. volume ratio. These show that for a given volume of reinforcement the best proportions tend toward a small ratio of OD to ID. The lowest stress index illustrated is 1.2 (compared with 3.0 for an unreinforced hole) and is obtained when the volume of reinforcement is four times that of the hole but the diameter ratio is only 1.2. With these proportions, the thickness of the reinforcement is over nine times that of the plate, again indicating an excursion beyond the bounds of two-dimensional theory. No consideration is given to the possibility of a critical stress occurring at any location other than the edge of the hole.

The theoretical work reported in this paper was supplemented by tests on an A 17S-T aluminum plate 16 in. wide, 0.0525 in. thick and with a free length of 32 in. Strains were measured both with Tuckerman optical gages and resistance gages, and the effective width of the plate was increased by riveting angles to the longitudinal edges. Eight tests were made: one with no hole in the plate; one with a 4.12-in. hole unreinforced; four with rings placed symmetrically on both sides of the plate, 5.50 and 7.10 in. OD attached with 10 and 20 rivets in a single row; one with the 7.10-in. OD rings attached with 40 rivets in two rows; and one similar to the latter except that one ring was removed, making the reinforcement unbalanced. This last test was run to destruction, which occurred at one end of the plate rather than across the hole. Measured strains were plotted and compared with theoretical strains deduced on the assumption of integral union between plate and rings. The inadequacy of the rivets was clearly shown in this comparison, as well as the fact that the 2-row arrangement of rivets came closest to the theoretical integral construction. The final test showed that with unbalanced reinforcement, bending moments are set up which tend to pull the plane of the reinforcement into the plane of action of the load; this corroborates the experience of other investigators, and agrees with theoretical results now being developed by the Pressure Vessel Research Committee.

Research by United States Navy

The next three items of interest suggest the importance of this subject of openings reinforcement quite beyond the field of tanks, pressure piping and chemical process equipment. In 1951, the Naval Ordnance Laboratory issued two reports authored by Tate,[5] giving a theoretical derivation of normal and shear stresses at the boundary between a so-called circular insert in a cylindrical shell, and the shell proper. Bending is neglected, and the treatment is simply that of a circular disk of thickness t_i and elasticity E_i butt-welded into a circular opening in a shell of thickness t and elasticity E, subjected to external pressure. It is assumed that an actual insert, such as a ring welded to an opening in the shell, to which is bolted a circular plate, may be correlated with a theoretical disk of stiffness E_it_i by suitable tests, to which the results given in the report would be applicable. It is further assumed that the two-dimensional, flat-plate analysis is applicable to the curved wall of a cylindrical shell up to ratios of insert-to-shell diameter not greater than $^1/_4$. Curves are included that give ratios of stresses at the insert boundary to the shell membrane stresses in the undisturbed region, versus stiffness ratios Et/E_it_i, and the point is emphasized that over-reinforcement may cause stress indices as severe as those produced by under-reinforcement.

Another report, released in 1956 by the David Taylor Model Basin, is noteworthy as being one of the few theoretical approaches that considers the openings problem from the three-dimensional viewpoint.[6] Galletly, in the first part of this report, gives a derivation of "edge coefficients" (i.e., displacement and rotation at a bounding edge due to unit moment or force at that edge) for a hemispherical shell having a circular opening at the crown. The basic differential equations used are those given in Timoshenko's "Theory of Plates and Shells," where the colatitude ϕ is the independent variable, and the transverse meridianal shearing force Q_ϕ and the rotation V of a tangent to the meridian are the dependent variables. Three methods of solution are demonstrated: (a) the Geckeler approximation, in which Q_ϕ and V and their first derivatives are neglected in comparison with their second derivatives; (b) the so-called Esslinger analysis (also used by Geckeler) where $1/\phi$ is substituted for cot ϕ; (c) the Love method, wherein an exact solution is obtained by first transforming the two basic equations to a single associated Legendre equation.

A numerical example is given for a hemispherical shell with 181-in. mean radius, 2-in. wall thickness, and 10.5 deg half-vertex angle subtended by the opening, and edge coefficients worked out by the three methods. It is concluded that method (a) is the simplest but gives errors up to 15%; method (b) is reasonably easy to use and gives errors of only -3%; method (c) is accurate if the Legendre functions are computed accurately, but this is extremely tedious since the functions are of complex degree. Method (b) is recommended, for values of ϕ up to 15 deg. An important part of the report is the inclusion of formulas for evaluating the stresses and displacements at the edge of the opening when it is joined to a cylinder of indefinite length; there is also an appendix giving two methods for computing the Legendre functions.

The design of openings may be of interest to the civil engineer, as evidenced by two contributions to "Engineering" (London) by Hicks, in 1953 and 1954.[7] The first article emphasizes the importance of reinforcement of circular openings in load-bearing concrete walls, box-type column foundations, etc. The slab is assumed to have the well-known two-dimensional stress distribution in flat plates with a central circular hole; in this case, the hole is reinforced with a hypothetical ring, very thin in the radial direction, that possesses tensile strength but no resistance to bending, in short, resembling Beskin's rim-without-ring combination. In practice, such a ring would be represented by steel reinforcing bars. By equating the radial force on an element of ring to the radial force on a mating element of the slab, and the tangential strain on the ring to the tangential strain on the slab at the same point, two boundary conditions are satisfied; all the remaining boundary conditions are fulfilled by invoking tangential equilibrium for an element of the ring, and finite stresses at infinity for the slab, tending to unidirectional tension and zero shear.

In the first article, formulas are derived for the radial, tangential and shear components of stress in the slab, both for the general case of any point, and for the particular case of the circumference of the hole. It is pointed

out that, with no reinforcement, the maximum stress is tangential in direction, located at the edge of the hole, and is three times the stress at infinity (the well-known stress index of 3). It is further stated that this stress can be reduced by adding reinforcement up to a point at which the maximum tangential stress equals the maximum shear stress; beyond this, additional reinforcement only aggravates the maximum stress in the slab. A formula for the optimum area of reinforcement indicates that it is approximately equal to ahE_c/E_R, where a = radius of hole, h = thickness of slab, and E_c and E_R are the respective Young's moduli for the slab and the reinforcement.

In the second paper, Hicks has extended his analysis to a reinforcing ring of constant (narrow) width but variable depth; by varying the depth in a manner similar to the variation of tangential stress around the edge of the unreinforced hole, reinforcing material is added, so it is claimed, at the points where it is most needed. An example at the end of the paper shows that, when such a ring of variable depth is used, the stress index may be reduced from 3 to 1.525, whereas a ring of the same weight but constant depth reduces the index only to 1.744. The analysis throughout both articles is strictly two-dimensional. In the example cited, the average depth of the reinforcing ring is over nine times the plate thickness, yet all elements of the ring, even those farthest removed from the middle surface of the plate, are given full credit for reinforcing capacity.

Work Sponsored by National Advisory Committee for Aeronautics

No review of openings investigations would be complete without referring to the work of Hoff and his associates at the Brooklyn Polytechnic Institute. This was sponsored by the National Advisory Committee for Aeronautics and the results, both theoretical and experimental, may be found in various NACA Technical Notes. Naturally, they show a decided slant in the direction of aircraft construction and are scarcely applicable to pressure-vessel design in the usual sense, but they are noteworthy as acknowledging without any reservation the fact that openings in the side walls of cylindrical shells present a three-dimensional problem. Technical Note 1014,[8] for example, considers the problem of stresses in a thin-walled shell stiffened by rings and stringers, in which a cutout has been formed by the removal of certain panels. The problem is solved by assuming each panel (rectangular portion of shell bounded by a pair of stringers and a pair of rings) as a unit having boundary stresses and displacements that are tied together by known linear relations. Furthermore, each panel is tied in with its neighbors by continuity of tractions and displacements at their boundaries, so that a set of linear simultaneous equations may be set up, the number of such equations being a function of the number of panels taken into consideration. Obviously, such a method can lead to a prodigious amount of computation, and the great value of the Note lies in its suggestions of means for making this as little burdensome as possible.

In another paper presented independently,[9] Hoff has outlined a procedure for designing reinforcements for cutouts in cylindrical shells of circular, elliptical, or any desired shape of cross section; the cutout also is not restricted as to shape. The method of analysis is to assume that the stresses in the shell should be unaffected by the presence of the cutout. To do this, a reinforcing ring is assumed at the edge of the cutout, and its cross-sectional dimensions are computed on the basis of a ring loaded by a distributed force equivalent to the stress pattern that exists in the uncut shell at the location of the edge of the cutout. This is a statically indeterminate problem, which the author solves by invoking the displacements of elements of the ring. For an arbitrary shape of cutout, and shells of noncircular cross section, the necessary integrations may be carried out numerically as indicated.

The paper is important for its acceptance of the fact that the openings problem involves more than simple plane stress. However, it appears that the method employed would not apply to pressure-vessel design except for very large openings in thin-walled vessels, where the reinforcing ring may be treated as a mere extension of the edge of the opening, with displacement of its elements so small that the assumed stress pattern in the shell is undisturbed, and where its cross section, instead of being constant, may be adjusted to suit the varying conditions of load and deformation that exist at different points around the perimeter of the opening. In fact, Marguerre, in a paper published two years previously where substantially the same analysis is used but is restricted to the case of two circular cylinders intersecting at right angles, stated that his "calculation is predicated on the assumption that this membrane stress pattern (in the undisturbed shell) is not materially affected by the elastic interference between the reinforcement at the opening and the thin wall of the vessel."

Almost without exception, theoretical attempts to solve the openings problem have assumed that the material remains wholly in the elastic state. However, NACA Technical Note 2073[10] offers a very ingenious procedure for finding the stress-concentration factor for the case of the hole in a flat plate, given any condition ranging from full elasticity to full plasticity across the critical section of the plate. The result is expressed in simple form: stress-concentration factor = $1 + 2E_s/E$, where E_s is the secant modulus at the critical point on the edge of the hole, and E is the secant modulus in the undisturbed region, presumably equal to Young's modulus. Factors computed from this formula were found to agree well with some experimental results on 24S-T3 aluminum sheet that had been reported in another Technical Note two years previously. A companion formula for plastic strain-concentration factor was also derived, but the agreement with experimentally determined strain factors was not quite as satisfactory.

Tests of Openings, 1930–50

In 1934, the present writer collaborated with J. Hall Taylor in the presentation of a report of one of the first comprehensive series of tests performed in this country on pressure vessels to which standard conventional nozzles were attached.[11] Test runs were started in 1931 and continued in 1932 and 1933, using three cylindrical test vessels (Fig. 3), each comprising a 42-in. ID shell with 2:1 ellipsoidal head at one end, the other end being swaged down to 34 in. ID and provided with a flat detachable closure permitting access to the interior. These vessels were each roughly 10 ft long, with wall thicknesses of $^3/_4$, 1 and $1^1/_4$ in. In all, thirty-six tests were made, including those on the vessel before holes were cut for the attachments. Of these, six were tests on the vessel with no openings; ten were tests of unreinforced openings with diameters of 7, 8, 9, 11 and 13 in.; six were on openings reinforced with sweep-type nozzles, six with straight-neck nozzles, five with welding necks, and two with welding nozzles; the maximum pressure was limited to maintain all points under observation within the elastic region. Finally, one test was run with all nozzles attached and 1000 psi pressure applied. An interesting commentary on the state of pressure-vessel design at this period is given by the fact that twelve of the attachments were riveted and only seven were welded. Also, strains were measured by Berry strain gages with 2-in. gage length applied at points on longitudinal and circumferential lines laid off on the outer shell wall and carried on into the reinforcement. This is perhaps one of the last large-scale test programs in which mechanical gages were used, and much of the scatter in the recorded results may be attributed to the difficulty of seating the gage points properly when moving the gages from station to station. Obviously, strains on the inner wall surfaces could not be measured, and

it would have been impossible to separate the membrane and bending stresses without measuring changes in curvature, in itself a procedure of doubtful accuracy.

The unreinforced holes that were located in the heads had diameters of 7, 8 and 9 in., and yielded stress patterns similar in form to that obtained for a circular hole in a flat plate with all-around tension; the disturbed region extended about the same distance from the edge of the opening, and the minor (radial) stress followed the theoretical values closely; the major (circumferential) stresses, however, instead of peaking at twice the undisturbed value, reached a maximum of 270% for the 7-in. hole in the $1^3/_8$-in. head, and 430% for the 8-in. hole in the $1^1/_8$-in. head and the 9-in. hole in the $^7/_8$-in. head. Much the same kind of result was obtained for the unreinforced openings in the shells; the area of disturbed stress values was about as theory would predict for a flat plate with central circular hole, 2:1 tension, and no lateral pressure, and the pattern of minor stress values also followed the predicted values for such a loading fairly closely. But the major stresses, instead of peaking at 250% on the longitudinal axis and 50% on the circumferential, rose in some cases to over 500% and 260% respectively. In view of more recent tests in which strain gages were placed on both exterior and interior wall surfaces, it is suspected that the maximum stresses at the edge of the openings, on the inside, were even higher than those just cited.

The welding necks were inserted in the openings flush with the inside of the shell, and welded inside and outside; two of these were thick-walled forged items, one of which (Series 30) was tested both with and without a reinforcing collar welded to the vessel at ID and OD and giving a two-fold increase in reinforcing area. A thin-walled (equivalent to extra heavy 6-in. pipe) welding neck, was also tested with and without a collar, the increase in area of reinforcement being practically four-fold. In all cases the peak major stress on the longitudinal axis was held to 130% of nominal value, or better, and on the circumferential axis there was marked improvement over the conditions for the unreinforced hole. The tests with collars showed a pronounced improvement in the region which they covered, but a very disturbing tendency to exhibit a peak just beyond the outside of the latter, that rose in one case to 235% of nominal hoop stress. The two welding nozzles, forged with tapered hubs and machined to fit the outside of the test vessels, also gave a good account of themselves; the best results of the entire series were obtained with the welding nozzle on the $1^1/_4$-in. wall vessel, where no stress greater than 120% of nominal was found at any point. Again, one must remember that these are *outside surface* stresses, and probably not the maxima.

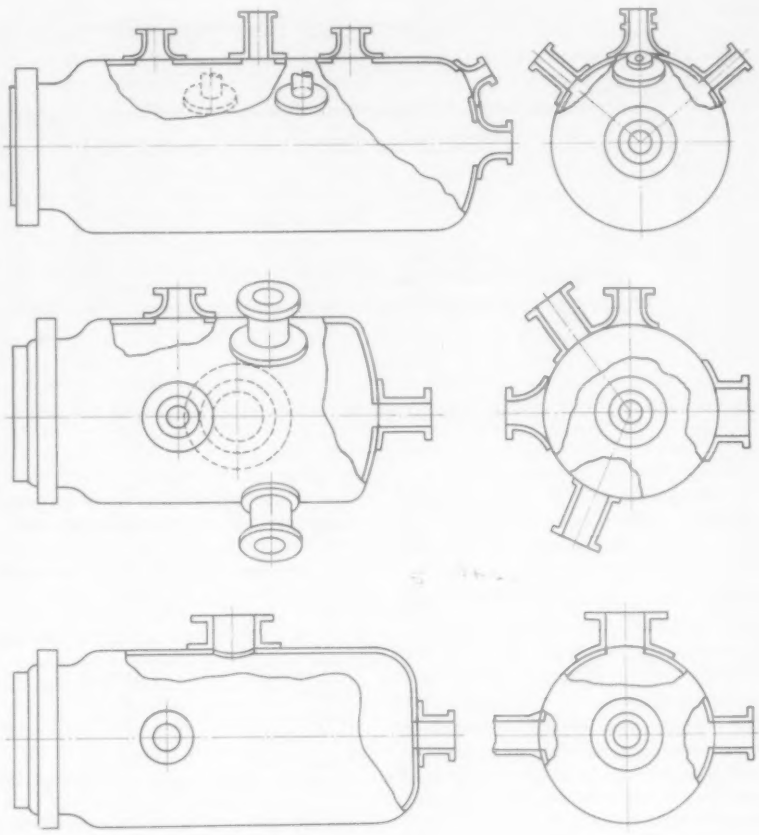

Fig. 3 Test vessels at Taylor Forge and Pipe Works

Considerable attention was given to the tests of riveted connections, and one test of a sweep-type nozzle stud-welded to the vessel in lieu of riveting. However, due to the obsolescence of these types of attachment, they need not be considered here. The general conclusions to be drawn from the entire test program corroborate those of similar programs conducted elsewhere, and confirm the following requirements for optimum design: thorough integration of reinforcement and main vessel; concentration of reinforcement as close to the edge of the opening as possible, both along the surface of the vessel and parallel to the axis of the hole; and avoidance of over-reinforcement resulting in the shift of stress concentration from the edge of the opening to a point farther out.

Several written discussions followed the presentation of the report of these tests, among which should be noted a theoretical contribution by Watts and Burrows, giving the results of studies in the Engineering Department of the Standard Oil Co. of Indiana, in progress since 1929. In this discussion, the equations for a symmetrically placed doubler, or pair of collars, were introduced, and solutions obtained for the integral doubler with all-around tension in the plate, and for a doubler with fillet of arbitrary angle at the OD; the effect of pressure on the edge of the hole was also included. These investigators concluded that such reinforcement cannot be perfect, a stress index of 1.3 should be acceptable; also, for large holes in thin plates, the reinforcement should be massed near the opening, whereas for small holes in heavy plates the reinforcement may be extended further out.

One year after the report of these tests, Hennes presented a doctoral dissertation to the faculty of the Technical Institute of Aachen, in which he described an investigation of stresses around openings in (A) the upper drum of a duplex fire-tube boiler, (B) a specially designed cylindrical test vessel.[12] The drum was 62.9 in. in diam with 0.77-in. wall, and approximately 10 ft long; it contained 52 fire tubes. Strain measurements were taken over a large surface near the 17.7-in. diam opening, in

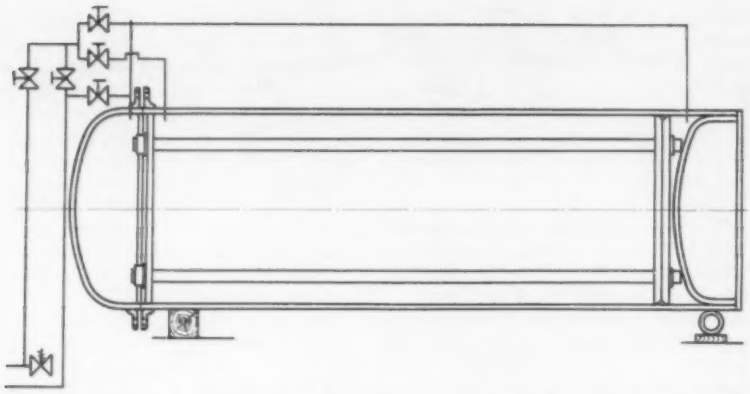

Fig. 4 Hennes' test vessel, with plates for separating hoop and longitudinal stresses

the longitudinal and circumferential directions, both with and without a nozzle riveted to the opening, using a mirror-type tensometer; results were displayed graphically by isometric charts that indicated very clearly the characteristic rise in strain near the edge of the opening. However, the influence of the fire tubes, the riveted collar around the opening, and the neighboring drum head, were all disturbing in the extreme, and no attempt was made to generalize the test results or draw quantitative conclusions.

The specially-designed vessel (part B) was 27.6 in. in diam with 0.44-in. wall thickness, and about 7½ ft long, and was designed with an ingenious method for securing pure longitudinal tension, pure hoop tension, or both, in the vessel wall. The arrangement, illustrated in Fig. 4, consisted of two floating plates, acting as pistons, inserted in the vessel near each end and held at a fixed distance from each other by six tie rods. This divided the vessel into three compartments, and by pressurizing various combinations of these sections, it was intended that the three kinds of loading could be effected. Unfortunately, the packing around the plates leaked to such an extent that pure longitudinal stresses could not be obtained.

The vessel was first tested without any openings, over a pressure range from zero to 213 psi; strains were measured at twenty-one stations covering the entire length of the vessel, with eight test points at each station covering a third of the circumference. At the mid-length, where the openings were later located, readings were taken around the entire circumference. Huggenberger tensometers were used throughout. The stresses computed from these observations agreed fairly well with the theoretical values, but there was a wide scatter among individual readings which the author attributed to out-of-roundness of the shell; his conclusions were partially substantiated by measurements taken around the outside of the vessel wall with a special curvature gage equipped with a dial indicator. On the whole, this part of the test was inconclusive, except to show the wide variation in test gage readings that can be obtained on a cylindrical shell in the as-fabricated condition, even after shake-down runs. Indirectly, they point out the incompleteness of a pressure-vessel test in which readings are taken on the outer surface only; had resistance strain gages been available, it would at least have been possible to arrive at the actual membrane stresses.

For the remaining tests, an opening was cut in the shell wall near its mid-length, having the following successive dimensions: 3.9-in. diam circular, 3.9- x 7-in. elliptical, 7-in. diam circular, and 7- x 9.3-in. elliptical. Again, readings were taken on the outside of the vessel over a 24- x 24-in. field surrounding the smaller circular opening; this was closed by a gasketed plate that was provided with a bolt and yoke in the conventional manner but was actually held in place solely by internal pressure.

The most significant results of the whole test program were those obtained from the strain readings taken around the circumference of the opening. For the smallest opening, these were taken on the outside only, but for the three other openings readings were taken on the outside, and also at points around the face of the opening approximately one-fourth and one-half way through towards the inside; from these, values for the stress around the opening, at the middle surface and at the inside, were derived by straight-line extrapolation. The results point emphatically to the large part played by bending stresses in the immediate neighborhood of the hole, and particularly at the inside edge on the longitudinal axis, where the resultant of membrane and bending stresses reached a maximum. This led the author to conclude that the best reinforcement should consist of a gradual increase of the wall thickness on the inside of the vessel, tapering from t at a point distant d from the hole center to 2.5 t at the hole edge (t = unreinforced wall thickness, d = hole diameter) but in no case to have less added area of cross section than that of the material removed. A summary of stress indices for the four openings follows:

	Stress index			
	on longitudinal axis			at Point of max stress on outside, measured from transverse axis
Opening	Outside	Middle surface	Inside	
Small circle	2.70	..	..	3.92, 45 deg
Small ellipse	2.26	3.80	5.70	4.80, 30 deg
Large circle	3.55	5.26	6.91	4.90, 45 deg
Large ellipse	2.38	4.74	7.09	5.80, 30 deg

As would be expected, still higher indices were obtained when the nut was screwed down on the yoke of the cover plate.

The importance of a study of reinforced openings in connection with power plant piping was pointed up by a series of tests reported by Everett and McCutchan in 1938[13]; these were run on an 8-in. header made of Schedule 80 seamless steel pipe, with an 8-in. welded branch connection, to determine the efficacy of reinforcement by means of a collar. Strain-gage readings, using a Huggenberger tensometer, were taken on one quadrant of the outside surface of the unreinforced construction, at fifty stations in the neighborhood of the weld, at pressures of 98 and 3510 psi. From these readings, the magnitudes and directions of principal stresses were computed, assuming perfect elasticity at all points. Runs were also made with a lateral load of 8000 lb at the end of the 3-ft long branch, both with and without internal pressure. A reinforcing collar, ⅝ in. thick, 2¼ in. wide at the crotch and 3¼ in. wide at the flat point on the side of the header, was then welded on and the tests repeated. The result was to reduce the maximum (apparent) principal stress from 65,700 psi to 22,000 psi; this was on the weld between header (or collar) and branch, about 1½ in. from the flat point. Exterior stresses at the crotch were comparatively moderate even without the

collar. The observers also noted that stresses in the header near the crotch were uninfluenced by the collar, but that near the flat point the stresses in the header just outside the OD of the collar were materially greater than before the collar was applied.

Several additional runs were made with a test pressure of 5060 psi, and finally a test to destruction at 8200 psi, which occurred as a characteristic tear along the side of the header tangent to the outer edge of the collar. The observers concluded that the ring-type of reinforcement was shown by these tests to develop the full strength of the uncut pipe. However, they admitted that their stress picture was far from complete, in that it was restricted to the outer surface of the header and branch and gave no clue as to the relative values of membrane and bending stresses. A rough method of separating these stresses was suggested: assume that the membrane stress pattern in the header can be represented by the infinite-flat-plate-with-a-hole solution, and that the difference between this and the experimental set of values for the outer surface gives the bending stress. The application of this method resulted in a very high inside stress at the crotch and a moderate stress at the flat, which was substantiated by the observed flattening of the header under high pressure into an elliptical cross section with the minor axis in line with the branch; this put tension on the inside surface at the crotch, and compression at the flat.

In 1940, Siebel and Schwaigerer reported a study carried out at the materials testing laboratory of the Stuttgart Technical Institute for the benefit of the German boiler industry.[14] Some preliminary tests were first made on steel plates 9.95 x 1.18 in. in cross section with a central 1.97-in. diam hole. When unreinforced, the stress pattern computed from strains measured on both sides of the plate with Huggenberger tensometers was much the same as predicted by the theory for the infinite flat plate under uniaxial tension. But with rings of varying thickness and OD and the same ID as the hole, welded to one side of the plate only, a great difference was noted between the stresses on the reinforced and the unreinforced sides, amounting in one case to a ratio of 1.6:1, and indicating a high degree of bending. In view of this, the subsequent tests were made with plates to which were welded inserted rings, in balanced position, whose proportions were based on a theoretical formula (derived in the report, but for all-around rather than uniaxial tension) relating the dimensions of the ring to the dimensions of the hole for a given stress-concentration factor. For a ring of approximately square section, tests showed that the stress-concentration factor was reduced to 1.45, and for a thin, long ring it apparently dropped below unity. The authors of the report warned that this value, obtained by strain readings at the edge of the hole, was illusive due to relaxation of the fibers of the ring that were far removed from the plane of the plate; they recommended that the dimension of the ring parallel to the axis of the hole should not exceed four times its width in the perpendicular direction, or alternatively, length not greater than $(b \times d)^{1/2}$. This is an early recognition of the applicability of cylinder shell theory to the reinforcement of openings.

Some pulsating load tests on plates, carried to failure, gave a very poor fatigue value to the plate with unreinforced hole; the plate with 88% reinforcement, balanced, was practically as good as the solid plate, while the plate with 176% reinforcement welded to one side of the plate lasted for little better than half as many cycles.

Finally, seven reinforced openings with extended branches, and two reinforced manways, in a $39^3/_8$-in. OD, 1.10-in. wall vessel, were tested at 100 atmospheres pressure. The openings were of various diameters ranging from 3.86 to 7.99 in.; one manway was elliptical and the other circular. As may be seen in Fig. 5, all reinforcements consisted of inserted rings, balanced, welded inside and outside, with the exception of two of the branch connections, one of which had no reinforcement other than the applicable portion of the vessel wall and branch itself and was fillet welded to the vessel on the inside only, while the other had an inside pad giving 100% reinforcement, on the area-replacement basis. All but one of the inserted rings were tapered on the outside so as to permit butt-welding to their respective branch pipes; they were all calculated (presumably using the authors' previously derived formula) to give zero to 15% maximum stress rise above the nominal values for an uncut shell; the manway reinforcements were calculated to give 32 to 36% rise. Actually, the test results came surprisingly close to the predicted figures for the inserted ring reinforcements, although it must be remembered that they were obtained on the outside surface only. Both the unreinforced and the inside-pad reinforced openings gave high stress concentrations, which were located at the crotch in the circumferential direction.

Transition from Mechanical to Electrical Strain Gages

About this time, resistance strain gages came into general use, replacing the cumbersome and less adaptable mechanical gages that had been the only practical means for measuring small deformations. One of the early uses of these gages in the United States, for experimentally determining stresses near openings in shells, was reported by Schoessow and Kooistra in 1945.[15] No internal pressure was used, and tests were for the purpose of investigating the effect of external loads at pipe connections, rather than reinforcing effects, and are therefore somewhat outside the scope of this review. The test model consisted of a 56-in. ID steel shell, 71 in. long, made by butt welding two semicircular halves, respectively, 1.30 and 2.08 in. thick, to which were welded two diametrically opposed pipes, each $11^3/_4$-in. OD, $^7/_8$ in. thick, and 90 in. long. The two pipes were loaded in tension, compression, longitudinal bending and transverse bending, and strain gage readings taken on the inner and outer surfaces of the shell covering one quadrant around each pipe and extending to a radius of 24 in. from the pipe axis. The authors made no formal analysis of their results, but noted that the strain gage readings indicated an exponential decrement of stress in the shell wall with increasing distance from the pipe axis, similar to that in a beam on an elastic foundation.

The names of Schoessow and Kooistra appear again in a pair of 1950 reports,[16] together with two of their associates, Brooks and Blaser. Kooistra

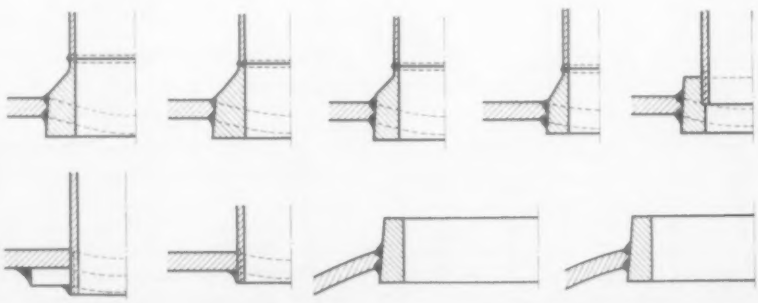

Fig. 5 Opening reinforcements tested by Siebel and Schwaigerer

tra and Blaser tested a number of full-size vessels at atmospheric temperature, and several $^1/_{10}$ scale models at elevated temperature, and commented in detail on the techniques used, such as: use of resistance strain gages, making it possible to record strains on the inner as well as the outer surface; design of a multi-lead leak-proof plug for the lead wires running to the inside gages and discovery that light lubricating oil is adequate as a high-resistance pressurizing medium; design of a balanced pulsator for fatigue tests, which when coupled to two specimens of the same capacity would require only the energy necessary to overcome friction. In discussing their results, the authors of this paper point out that there is no significant difference between the endurance limit of room-temperature models and elevated-temperature models, but that the endurance limit for all models tested was well below that of flat plate specimens. It was also noted that a slow cycling program, with rest periods at maximum and minimum pressure, was more severe than the continuous cycling provided by the pulsator.

Schoessow and Brooks analyzed the results of the static tests on the foregoing specimens, and presented their findings in terms of T/PR for membrane load and M/PR^2 for bending load for each head or nozzle opening of a given geometry (T = tension per inch of circumference, M = bending moment per inch of circumference, P = pressure, R = inside radius of shell). The first of these dimensionless quantities equals unity for a cylinder in the circumferential direction, and 0.5 for a sphere or for a cylinder in the axial direction; the second equals zero unless there are discontinuity stresses. Accordingly, their deviation from these values indicates the degree of stress concentration for the point at which they apply. The major results of this analysis may be summarized as in the table below:

Item	*Max T/PR*	*Location*	*Max M/PR^2*	*Location*
Shallow head with elliptical flued-in manway, 1906	5.3	Knuckle of manway on major axis	0.043	Knuckle of head on major axis
Shallow head with flued-in manway, 1950	3.1	Same as above	0.016	Same as above
2:1 ellipsoidal head with circular manway reinforced with equal-dilation ring	1.3	Adjacent to ring-to-head weld	0.011	Approx. 0.9 of head diameter
Hemispherical thick head with unreinforced circular manway	1.2	Near manway and near skirt	0.011	Near manway
Inserted straight nozzle, 106% reinforcement, balanced	2.06	Edge of hole, on longitudinal axis		
Inserted tapered nozzle, 115% reinforcement, balanced	2.04	Same as above		
Inserted nozzle and integral reinforcing ring, reinforcement 194% within 2D, 302% total, balanced	1.51	Outside of ring, on circumferential axis		Note that over-reinforcement shifts the location from the edge of the hole to a point in the shell outside the reinforcement
Inserted nozzle and integral reinforcing ring, reinforcement 147% within 2D, 380% total, balanced	1.26	Same as above		
Elliptical nozzle, 16% reinforcement, balanced	1.40	Edge of hole, on longitudinal axis (= minor axis of ellipse)		
Elliptical nozzle, 113% reinforcement	1.19	In shell outside of nozzle, on circumferential axis (= major axis of ellipse)		

The 1906 drum, whose head is the first item in the foregoing table, had been in continuous service until 1948, had undergone about 75 cycles to 300 psi pressure ($1^1/_2$ times operating pressure) and several thousand cycles to 200 psi. It showed no ill effects from corrosion and was apparently in good shape for continued service. Examination of the T/PR and M/PR^2 plots showed that local areas of the head had undergone a stress range of slightly over twice the yield point of the material; this, in the authors' opinion, appears to be satisfactory for boiler drums made of mild steel.

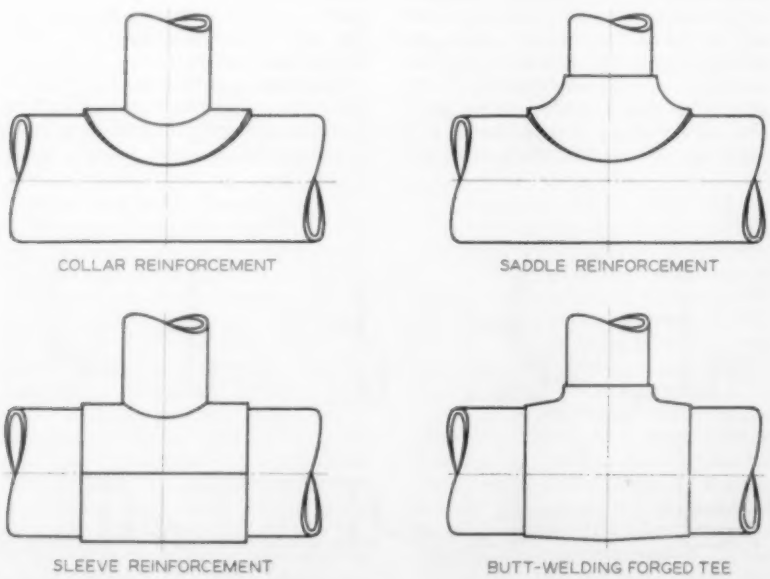

Fig. 6 Typical pipe-line connections

Ship Structure Research

The ship-building industry has spent much time and effort in a study of notch effects and stress concentrations in the welded-hull structure of sea-going vessels, with the aim of eliminating the likelihood of structural failure under all conditions of service. Some of this work has extended into the proper design of openings, and a representative paper dealing with investigations in this field appeared in 1951 under the authorship of Vasarhelyi and Hechtman.[17] A series of tests was performed on $^1/_8$-in. steel plates to determine the effect of round, square and square-with-rounded-

corners openings, with and without reinforcement, under the sponsorship of the Bureau of Ships, United States Navy. The plates were 36 in. wide and 7 ft long between pulling heads, and were tested uncut, and with central circular holes of 9 in. diam and square holes 9 x 9 in. with corner radii of $^1/_{32}$, $^3/_{16}$ and $1^1/_2$ in. Reinforcement was obtained either by "face bars" (the equivalent of short lengths of pipe extending equal distances beyond each side of the plate) fillet-welded on both sides, by a single doubler plate fillet welded to the main plate at the OD and edge welded at the ID, or by an inserted plate butt-welded or fillet-welded to the main plate.

The results are graphed and tabulated in an unconventional manner. Instead of giving stress-concentration factors for purely elastic conditions, the investigators have assumed that better criteria of service performance could be obtained by relating the yield strength, ultimate strength and energy-absorption-to-failure of the specimens with openings to the corresponding properties of the solid plates. Since these properties all involve plastic yielding across a part or all of the cross section of a plate, they give totally different numerical ratios from those normally associated with a stress-concentration factor. For example, the plate with the unreinforced circular hole would give a stress-concentration factor of approximately 3 under fully elastic conditions, yet the ultimate strength of this plate actually turned out to be no less than that of the uncut plate (using the original *net* area in both cases). On the other hand, strain energies to fracture were greatly impaired by all the openings, whether reinforced or not; the best value obtained on any of the tests was a ratio of 26%, for a 9-in. round hole reinforced with a 9- x 18- x $^1/_8$-in. doubler plate (102% reinforcement, including weld metal). Some of the significant conclusions were: (1) ultimate strength of plates with openings ranged from 75 to 100% of that of the solid plates, being best for the round openings and decreasing linearly with log R_o/R_N for the square plates, where R_o = half width of square and R_N = corner radius; (2) the corresponding range for energy absorption was 9 to 26 percent, with a similar relation to log R_o/R_N; (3) increase in reinforcement improved the ultimate load capacity but decreased the ultimate strength. Although numerous strain-gage readings were taken in the direction of the load in the neighborhood of the openings, these were not emphasized in the report except to show by graphs how the strain rose from a low value at the edge of the plate to a high value at the edge of the hole, with an additional peak, in the case of the openings with doubler plates, at the outer edge of the latter.

This investigation calls to mind a somewhat similar series of tests reported in a NACA Technical Note by Ruffner and Schmidt,[17] in which photoelastic models of plates with holes of various shapes—circular, square and rectangular with rounded corners, unreinforced and reinforced with integral doublers—were examined to determine stress-concentration factors. The results, however, are not comparable since the models were tested in shear instead of tension. It is interesting to note that the circular cutouts gave the best performance; also that the square cutouts were less objectionable stress raisers if set with diagonals, rather than sides, parallel and perpendicular to the sides of the plate.

The design of the penstocks for the hydroelectric plant at Boulder Dam, for which Hollister acted as consultant,[18] involved the careful study of stresses in special openings of large size and unusual shape, 30- x 13-ft branches, 2- and 3-way reducing wyes, etc., all of which had acute angles between branch and header and would not be considered as having any close connection with conventional pressure-vessel design. Elaborate investigations were made, ranging all the way from photoelastic tests of plates with holes to photoelastic tests of model headers with branches and physical tests of scaled-down steel vessels, and including considerable mathematical analysis. To determine the best manway design, twenty photoelastic models were tested, giving stress-concentration factors at the edge of the hole on the longitudinal axis of 1.0 to 2.74. The final design comprised a 16- x 20-in. elliptical opening, reinforced with a diamond-shaped pad on the outside, roughly 3 x 4 ft across corners, and an elliptical pad of comparable size on the inside; both pads tapered gradually from full thickness next the opening to zero at the outside.

A by-product of the foregoing photoelastic studies, worth mentioning here, is a formula derived by Hollister and Schoessow[19] for the stress concentration caused by a hole of diameter d in a plate of width W; stress-concentration factor, based on net section of plate, $= 3 - \frac{1.6\ (8\text{-}W/d)^{3.6}}{1100}$ for W/d from 1.5 to 8; for W/d greater than 8, the classical value of 3 holds true.

Recent Developments; Transmission Pipe-Line Research

British investigators have shown an increasing interest in pressure-vessel research during the past decade, a good share of which has been directed towards a better understanding of conditions around openings. A concise review of this activity, as of 1954, is contained in an article by Gross[20] in the British Welding Journal. After a brief résumé of testing methods and theoretical background, he mentions some of the pressure-vessel tests in Great Britain subsequent to 1946, noting that the first of these were on drumheads with and without manholes and confirmed the results of Siebel's tests; the prevalence of high bending stresses along with membrane stresses in the region of the opening is pointed out, and the suggestion made that the factor of safety for the former be made one-half of that for the latter. Coming to the topic of openings in the cylindrical portion of vessels, Gross describes a major experimental program carried out in 1946 and 1947 at the Babcock and Wilcox, Ltd., plant, in which three 12-in. ID nozzles with $1^5/_8$-, 1- and $^3/_8$-in. wall thickness, welded to a 42-in. diam header, were tested under static pressure conditions, with strain gages attached to header wall and nozzle, both inside and outside, along the two lines of symmetry. The discrepancy between inside and outside gage readings at the same location showed that high bending stresses existed close to the weld, and that while an increase in nozzle wall thickness helped somewhat to reduce the maximum over-all stress (which occurred on the inside at the crotch) it did little if anything to mitigate the bending component. With regard to branches in pipelines, the article makes the point that here the analogy with the hole in a flat plate fails to hold true, due to the large size of the openings in relation to the header diameter; there are also secondary effects such as the tendency to bulge outwards on the unsupported sides, exemplified most forcefully by the tee connection with branch diameter equal to that of the header. A brief account is given of a current research program of the British Welding Research Association (BWRA), the first stage of which concerns the general efficacy of welding tees formed by extruding the side opening from a straight run of pipe. Here again there are high bending stresses and a high factor of stress concentration, if the maximum stress is compared with the nominal stress in a straight pipe of equal wall thickness; however, this would normally be reduced to a workable figure by using such a tee with pipe of much less wall thickness in the run and branch.

In another article appearing a year later,[21] Carlson and McKean discuss three topics related to pressure-vessel design: (a) experimental evidence that stresses due to out-of-roundness of a shell may be accurately predicted by Haigh's analysis (this has also been uppermost in some of the BWRA research); (b) correlation of strain-gage readings on drumheads with computations by the beam-on-elastic-foundation analogy; (c)

stress concentrations caused by elliptical manholes in drumheads. In this last section, the authors report the results of tests on fourteen vessels, twelve of which had conventional flanged-in elliptical manholes, while the remaining two had manholes reinforced on the outside with fillet-welded rings giving 64 and 100% reinforcement, respectively. All but two of the openings had a 4:3 ratio of major to minor axis, and the heads varied in depth and wall thickness. In almost all cases, the point of maximum stress concentration occurred at the edge of the hole, on the outside surface and on the major axis, the only exception being the 100% reinforced manhole where the point was moved to the outer edge of the reinforcing ring, and the maximum stress was radial instead of circumferential. Stress indices ranged from 7.80 for the shallowest head (h/D = 0.12) with flanged-in manhole, to 1.58 for the fully-reinforced manhole in a head having h/D = 0.31. These values were computed on a maximum-shear-strain-energy basis; the corresponding indices figured on the more customary maximum-normal-stress basis are slightly lower.

The BWRA research program previously referred to is a continuing activity, and under the direction of its FE.12 Committee on Stresses in Welded Pressure Vessels is directing much attention to the problem of openings. Most of the reports of this committee are available to members of the Association only, but it may be stated that thus far, tests of nozzles on a 42-in. diam vessel indicate that balanced reinforcement is advantageous from a stress standpoint. The program also includes pulsating pressure as well as static tests, and tests of header-branch connections with a 1:1 diameter ratio.

The tremendous increase in long-distance pipe lines for oil and gas since World War II has brought into sharp focus the problem of design of openings, particularly with reference to branches taking off from main lines or headers, where field-welded connections are the accepted type, made either during construction of the line or later under hot-tap conditions. Figure 6 illustrates four types of connection in common use. Recognizing the need for study in this field, five major gas companies sponsored a program at Battelle Memorial Institute beginning early in 1951 and continuing until late in 1955, with some changes in organization that finally brought in the American Gas Association as primary sponsor.

The program falls naturally into three divisions: Part I covers static tests on unreinforced branch-to-header connections; Part II continues with static tests on reinforced connections; and Part III, which was conducted by Tube Turns as part of another program, comprises a series of pulsating load tests.

In Part I, some strain-gage measurements were first made on seven branch connections in the field, as a preliminary guide to the kind of loading that might be expected on a typical underground branch close to the header. This was followed by the main portion of the work, which consisted of strain-gage tests on three sizes of branch connections (4 in. Schedule 40, 12 in. Schedule 20, and 24 in. x 0.321 wall API—5LX specification pipe) welded to a 24-in. header of the same wall thickness and specifications as the 24-in. branch. Readings were taken with rosette gages, so as to determine principal stress magnitudes and directions, on the branch, along the zero degree line (formed by the plane normal to the header axis), the 90-deg line (formed by the plane containing the header axis), and on one or more intermediate lines (usually 30 and 60-deg) as experience dictated. These gage lines were continued on the surface of the header as helices having 0, 30, 60, etc., degree lead angle, and extending far enough from the weld line to determine the extent of the region affected by the opening. Loading consisted of internal pressure, and bending applied to the branches in the axial and transverse directions. No gages were placed on the inner surfaces of the specimens.

It was found, first of all, that the region of high stress was confined to a narrow band close to the weld line, and dropped to the nominal value for uncut pipe within one branch diameter from the weld. Secondly, the maximum stress increased with increasing branch-to-header diameter ratio. Finally, the maximum stress, for loading by internal pressure, was on the zero degree line at the branch side of the weld and on the 24- x 24-in. specimen, reaching a value of five times nominal hoop stress in the header. The other two specimens reached maxima of about 1.6 to 2.4 times nominal, with no characteristic variation around the weld from 0 to 90-deg. The transverse bending tests gave much higher maxima: 6.5 times nominal bending stress in branch for the 4- x 24-in. specimen, up to 12.3 times nominal for the 24- x 24-in. combination; the maxima for axial bending were not significantly higher than those for internal pressure.

After the strain-gage tests, all specimens were pressurized to destruction. The bursting pressure for the 4- x 24-in. connection was substantially that which would be predicted for the uncut pipe, while for the 24- x 24-in. specimen it dropped no lower than 85%, indicating the vast difference in stress distribution before and after yielding takes place.

In Part II a much more comprehensive program was undertaken, using three vessels (4-, 8- and 12-in. branch x 24-in. run) with saddle reinforcement fillet welded to the pipes at each edge, three vessels of the same dimensions with pad reinforcement welded at inside and outside edges of the pad, and one 12- x 24-in. diam specimen with a full encirclement sleeve split on the 3 o'clock and 9 o'clock planes, the two halves being butt welded together and the upper half containing the opening for the branch being welded at that point to the branch and header. In all cases the reinforcement was superposed on an unreinforced welded joint between branch and header like that used in Part I, and met the ASA requirements on an area-replacement basis. Internal pressure and bending loads were applied as in Part I, and the report of these tests gives a very complete summary of the maximum principal stresses obtained on each helix angle, together with their location on each helical line, and their direction. It should be noted that internal gages, as well as external, were used in these tests; however, they were only single-element units and were placed only at the 0 and 90-deg gage lines where the directions of the principal stresses could be taken for granted. Water was used for pressurizing the vessels, as in Part I; special precautions were taken to insulate the internal circuits, apparently with good success.

A second run was made with the sleeve-reinforced vessel, after fillet welding the sleeve to the header at its free edges, but no significant improvement was recorded. All vessels were also given a high-pressure test designed to produce a nominal stress in the header of 90% of minimum specified yield strength; this developed appreciable local yielding in the 12- x 24-in. specimens but very little in any of the others. The report of this part of the program records these major findings, for loading under internal pressure: (a) The three types of reinforcement gave maximum stresses in the following descending order of magnitude: saddle, pad, sleeve. (b) All reinforcements developed maximum stresses lower than those for the corresponding unreinforced connections, with one exception which may be explained on the basis of a (probably) high stress on the inner surface that was not measured. (c) The effect of branch-to-header diameter ratio was of the same type as for the unreinforced connections. (d) For the pad and the sleeve reinforcements, the maximum stress is circumferential, and on the header; this latter is also the location of the maximum stress for the saddle reinforcements. (e) A good fit-up and close clearance between reinforcement and pipe wall is essential in keeping stresses to a minimum.

Part III of the AGA program com-

prised a pressure-pulsation test to failure of the seven vessels of Part II, carried out at the Louisville, Kentucky plant of Tube Turns, and may best be described as Series II of the Tube Turns program. Briefly, this program was intended to furnish data for the improvement of branch connections to headers, using cyclic pressure and bending tests on welded connections of several proposed designs. The pulsating pressure tests were performed on a section of 22-in. diam x $^{9}/_{16}$-in. wall rolled-and-welded pipe, and on eleven variations of branch connection ranging from the typical unreinforced joint to butt-welding forged tees and manifold fittings with extruded outlets for butt welding to branch pipes. For convenience, the assemblies were grouped in three series, and in all but a few cases were tested to failure. After testing, an average cyclic life of the saddle-reinforced assemblies was figured out. Taking this as a standard, the cyclic lives of the other designs were assigned a relative value and arranged (in the Tube Turns report) in descending order of merit. Naturally, the uncut pipe stands at the top of the list and the unreinforced connection at the bottom. The pad and the encirclement sleeve designs rated about the same as the saddle. Of the other types, the butt-welding tee, the full-encirclement saddle, the plain encirclement sleeve combined with a plain saddle, and the manifold with extruded outlets, gave the best performance and were to all intents the equivalent of uncut pipe in endurance. The authors of the test report noted that, where strain-gage readings were available, they gave an accurate prediction of the location of failure in a cyclic pressure test; in other words, static strain-gage tests and cyclic pressure tests to failure are correlatable. On the other hand, all the fabricated connections used in the tests were over 100 percent reinforced according to the ASA Code for Pressure Piping rules and were presumably equal to uncut pipe in static strength, yet there was no relation between amount of reinforcement and cyclic life.

Another investigation of somewhat similar pipe assemblies was reported by Barkow and Huseby in 1955. In Part I, which is that portion of the research of most interest here, a study was made of the stress pattern and bursting strength of field-welded header-to-branch connections reinforced with collar, saddle and full-encirclement sleeve. Six assemblies were tested; all except No. 6 (the full-encirclement sleeve) showed a high stress in the header at the toe of the fillet weld to collar or saddle, on the zero degree line, and the three that showed the highest stress at this point failed at the same point in the burst test. However, all but one developed the full strength of uncut pipe in the burst test, confirming that the saddle or collar reinforcements are adequate for static loads.

Conclusion

Clearly, it is impossible in a review of this scope to comment on all of the experimental and theoretical work on pressure-vessel openings that has been carried out since 1930. Doubtless a considerable amount of it is confidential and remains the private property of pressure-vessel manufacturers and users. The researches that have been included here are set forth in detail in readily available publications, and are listed in the appended bibliography.

It is evident that much work has been done, but that much has still to be accomplished. We know that, as far as theory is concerned, the two-dimensional flat plate approach is only a guidepost and should be supplemented by three-dimensional solutions that will fit conventional openings and connections on the side walls of cylindrical shells. Furthermore, such solutions must be in a form that designers and code-making bodies can understand and use. On the experimental side, there is a mass of uncorrelated data, obtained by researchers interested only in a particular application, and therefore only of value in a limited field. Certain qualitative results are common to all tests: the region of disturbed stress is confined roughly to a circle of twice the diameter of the opening; the stress index increases as the ratio of opening-to-vessel diameter increases; the effectiveness of reinforcement is enhanced by its closeness to the edge of the opening; there is danger of high stress at the outer edge of a pad or saddle; all these are well established facts. It remains to find a reasonably accurate numerical value for the stress rise caused by openings, either unreinforced, or with any one of a few conventional types of reinforcement, such as the group of four shown in Fig. 7, which are representative of configurations now being studied by the Pressure Vessel Research Committee. This, together with an extension of the theoretical approach and the correlation of theory and experiment, is the present aim of the Committee, working through the Subcommittee on Reinforcement of Openings of its Design Division.

To carry out this program, research is being supported at the University of Illinois, Pennsylvania State University and Yale University. At Illinois, photoelastic tests are under way on scale models of spherical vessels with attached nozzles having various shapes of reinforcement; many of these are of particular interest to the Bureau of Ships of the United States Navy, and have been designed to meet specific problems of that service. Full-size steel vessels with welded-on branches are being tested at Pennsylvania State, while at Yale, photoelastic studies of reinforced openings in flat plates are in progress, together with a development of theory which aims to take full account of the three-dimensional nature of the problem.

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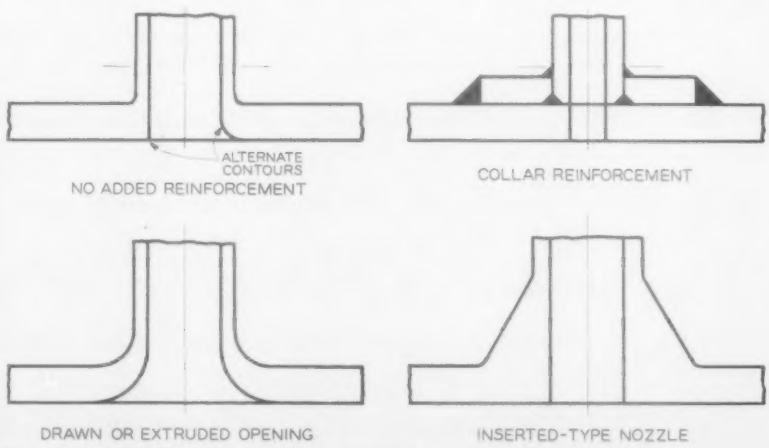

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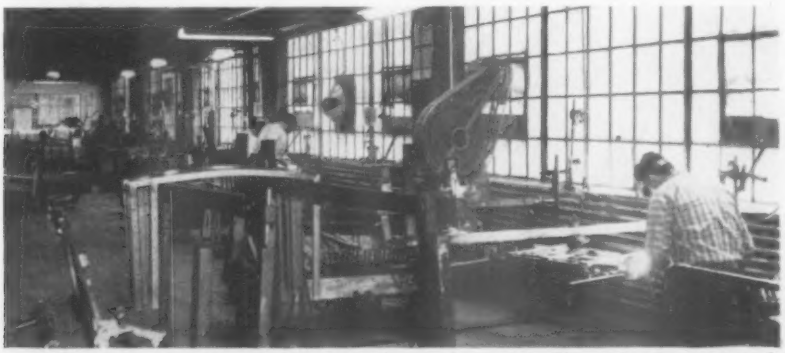

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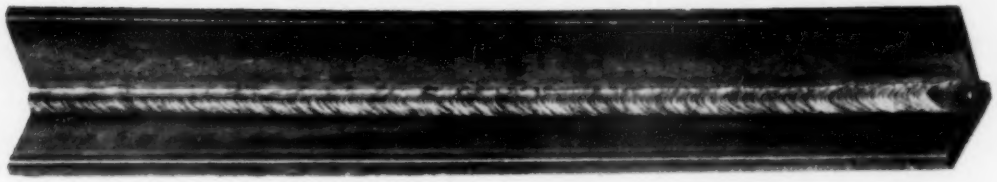

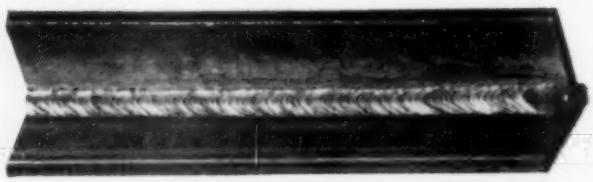

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